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Boulder Laboratories

MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE 4 - JUNE 1959

BY J.W. WRIGHT, L.R. WESCOTT AND D.J. BROWN

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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NATIONAL BUREAU OF STANDARDS

Technical Note

40-4

May 1961

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by

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Central Radio Propagation Laboratory

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ABSTRACT

The CRPL has initiated a program for large-scale computation of electron density profiles from ionospheric vertical soundings. Scaling is performed at field stations, permitting computation of hourly profiles at the Central Laboratory. These profiles are combined to form hourly mean quiet profiles for each station and month. The results of this program for the month of June are illustrated graphically. This report is the fourth of a series illustrating the electron density variations in the mean quiet ionosphere between latitudes 15°N and 50°N along the 75°W meridian.

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MEAN ELECTRON DENSITY VARIATIONS OF THE QUIET IONOSPHERE 4 - JUNE 1959

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I Introduction

Part of the basic responsibility of the Central Radio Propagation Laboratory is to gather ionospheric, solar, or other geophysical data necessary in the pursuit of research leading to improvements in radio communication and knowledge of the earth's upper atmosphere. The existing network of ionospheric vertical sounding stations is an important source of such data. Typically, the radio sounding data directly provide observations of peak electron densities (corresponding to "critical" frequencies foE, foF1, foF2), data on Sporadic E, and certain derived propagation data such as maximum usable frequencies or MUF factors (Smith, 1939).

In fact, the vertical sounding is potentially capable of providing the complete electron density profile of the underside of the ionosphere (i.e., below hmaxF2), and of providing a basis for extrapolation to much greater altitudes. However, because a lengthy and difficult calculation is required, little of this work had been done until quite recently when techniques and computers have become available and the exigencies of the IGY and satellite programs have made it imperative.

In the course of its development of facilities for electron density profile calculations, the CRPL has succeeded in devising means by which basic data for this purpose may be scaled by the individual field stations, thereby decentralizing and simplifying the most onerous part of the work. Through its own station network and those of the U. S. Army Signal Radio Propagation Agency, and through cooperation with closely associated stations in other countries, the CRPL has initiated an extensive systematic data reduction program, from which hourly electron density profiles are being computed for the following stations:

Puerto Rico (NBS, January 1959)
Grand Bahama Island (U. S. Army Signal Corps, February 1959)
Fort Monmouth, New Jersey (U. S. Army Signal Corps, Feb. 1959)
White Sands, New Mexico (U. S. Army Signal Corps, March 1959)
St. Johns, Newfoundland (Def. Res. Tel. Establ. Canada, June 1959)
Adak, Alaska (U. S. Army Signal Corps, June 1959)
Okinawa, Ryukus (U. S. Army Signal Corps, June 1959)
Thule, Greenland (U. S. Army Signal Corps, July 1959)
Bogota, Colombia (January 1960)
Huancayo, Peru (January 1960)
Talara, Peru (January 1960)
Baguio, Philippines (February 1960).

Affiliation and approximate date of initial participation in this program are given in parentheses.

The hourly electron density profiles are extensively used in the research programs of CRPL and are supplied directly to certain other agencies as part of various research and practical activities. However, in this comparatively early stage, broad dissemination of the computed data is a somewhat difficult problem.

In an attempt to make at least a summary of the results of the program widely and rapidly available, the CRPL has initiated the present series of reports. These provide graphical representations of the monthly mean quiet hourly electron densities from certain of the stations in the preceding list, from which a fairly clear picture of the local ionosphere morphology may be obtained.

These reports contain N(h) data for the stations at Newfoundland, Fort Monmouth, Grand Bahama Island, White Sands, and Puerto Rico. Pertinent facts concerning these stations are given in the following table:

Table 1

Station	Geomag. Coordinates fH	Lat.	Dip	Geog. Coordinates	
St. Johns, Newf.	1.38Mc/s	58.5°N	72°N	47°33'N	52°40'W
Ft. Monmouth, N.J.	1.46	51.7°N	71.5°N	40°15'N	74°01'W
White Sands, N.M.	1.30	41.2°N	60°N	32°24'N	106°52'W
Grand Bahama Island	1.30	37.9°N	59.5°N	26°40'N	78°22'W
Puerto Rico	1.15	30°N	51.5°N	18°30'N	67°12'W

II Description of Basic Data

True heights of reflection of radio waves are calculated from the observed or "virtual" heights by the method of Budden (1954); this method need not be described here except to point out that full correction for geomagnetic field effects is made and that the usual restrictions to monotonic profiles apply.

Tabulations of the mean electron density data at 10 km intervals and certain related quantities are the bases for the graphs and charts. A sample for the Puerto Rico June data is given on Page 11. The table on the following page identifies the quantities appearing on the tabulation.

TABLE 2

Quantity	Units	Remarks
Average Electron Density (N)	$x10^3$ = electron/cm^3 (10^{-5} on maps)	Body of table; given at each 10 km of height from the lowest hmin to 950 km.
NMAX	$x10^3$ = electron/cm^3 (10^{-5} on maps)	The mean value of Nmax.
COUNT		Count of the number of profiles entering the mean.
HMIN	Kilometers	The average height of zero or very low electron density, obtained by linear extrapolation of the electron density of the individual profiles.
HMAX	Kilometers	The average height of maximum electron density, determined by fitting a parabola to the upper portion of the individual profiles.
SCAT	Kilometers	One half of the half-thickness of the parabola best fitting the upper portion of the F-region profile. Approximates the scale height near the true HMAX.
SHMAX	$x10^{10}$ = electrons/cm^2 column (10^{-12} on maps)	Obtained by averaging the integration of the individual profiles between the limits HMIN and HMAX.
SHINF	$x10^{10}$ = electrons/cm^2 column (10^{-13} on maps)	The average total number of electrons in a column to infinity obtained by extrapolation of observed profiles into the region above HMAX. (See text.)

The following particular features of the tabulated data should be noted:

A. Averaging process. Each hour of each day is identified with its magnetic character figure, Kp. For each hour, those days for which Kp is less than 4+ are included in the "quiet" average. The other days are similarly combined to form a "disturbed" average; however, this rarely has physical significance because the number of distrubed periods is usually small and the behavior of the ionosphere during disturbed hours is not consistent. Thus graphs for these latter averages are not presented here.

B. Determination of hmax. The nature of the "true height" process is such that no direct measure of hmaxF2 is obtained, the virtual height at Nmax being immeasurable. A useful procedure is to fit the portion near hmaxF2 with a suitable curve and to determine hmax from this curve. A parabola is quite satisfactory for this purpose; it is fitted to two of the highest true heights and the measured value of Nmax(foF2).

C. Extrapolation of profiles above hmax. Before averaging, the individual profiles are extrapolated above hmax by a Chapman distribution of 100 km scale height. This assumed model seems to agree well with the few published measurements dealing with the profile of the F region above hmax (Wright, 1960). Extrapolation is necessary in order to calculate homogeneous averages near hmax, and the average profiles are, in fact, given to 950 km.

D. Integrated Electron Densities. The total number of electrons in a unit column of the ionosphere between the effective bottom (hmin) and hmax is called Shmax; it is obtained by numerical integration of the observed profiles between these limits. An estimate of the total electron content to infinity, based upon the Chapman model, is called Shinf. It is obtained by adding to Shmax the quantity $N_A = 2.82\ HNmax$ where H is an (assumed constant) scale height for the region above hmax. Current evidence

(Wright, 1960) indicates H = 100 km, is an acceptable choice.

III Description of Graphical Representation

The relative smoothness of mean quiet ionosphere data lends itself to various kinds of graphical presentation which offer convenient aids to the visualization of the height, geographic, and temporal variability of the ionosphere. Three such graphical forms are included here, prepared from the tabulations described in Section II.

A. Vertical cross sections of the ionosphere along the 75°W meridian. Pages 12 through 35 give for each hour, a vertical cross section of the mean quiet ionosphere along a meridian section, nominally the 75°W geographic meridian, for the month of June 1959. Contours are parametric in "plasma" frequency (f_N) related to electron density N by

$$12{,}400\ f_N^2(\mathrm{Mc/s}) = N(\mathrm{electrons/cm^3}).$$

The height of maximum electron density is represented by a dashed line. Note that the vertical scale is expanded about 5.5 times.

With the exception of White Sands, each of these stations is reasonably close to the 75°W meridian (see Table 1). There is the possibility that some of the anomolies imposed by White Sands on these contours are the result of the well-known longitudinal asymmetry of the ionosphere.

B. Local time vs Latitude Maps. Another form of presentation, useful for indicating the two-dimensional geographic variations of the ionosphere, is that illustrated by the maps of pages 36 through 45. Here, for fixed levels in the ionosphere (150,200,250,300,350, 400 km), contours of electron density are drawn in the latitude vs. local time plane. To the extent to which longitude anomalies are negligible, these maps give also the longitude vs. latitude

distribution of electron densities at the indicated heights when it is noon over the 75°W meridian. Similar maps for the peak density, Nmax; its height, hmax; its characteristic thickness, Scat; the total electron content to Nmax, Shmax; and the estimated total electron content, Shinf, are also shown.

C. Electron density vs. time curves (N(t) curves). The mean quiet diurnal variation of electron density between 150 and 400 km heights above the sounding stations is illustrated by these curves. Dashed lines are used wherever the electron density at any height falls below the peak density (i.e. when the height hmaxF2 falls below the height for the curve in question.) Such electron densities are the result of the extrapolations by the Chapman model discussed in Section II C.

IV Discussion and Applications of the Data

Mean quiet electron density data over wide geographic areas are essential for application to numerous problems of both practical and scientific interest. For example, the assessment of the radio refraction errors and Faraday rotation effects in satellite tracking require a knowledge of the electron density profile in the direction of the satellite or an estimate of the electron density at the satellite itself. Alternatively these properties of the ionosphere, or estimates of the total electron content in a column, may be measured by observations from rockets and satellites, or from radar moon-echoes, and compared with ground-based observations of the kind shown here.

Frequently it will be necessary to use instantaneous density data because of the considerable variability of the ionosphere about the quiet mean. In such cases, the mean data are of value as a "reference level" in the design of the experiment; for example, in the choice of radio frequencies. satellite heights, antennas, etc.

Since electron density data represent virtually our only source of continuous, widespread data on the earth's upper atmosphere, such data also are essential to geophysical problems involving the electrical, neutral, and magnetic properties of the atmosphere.

For example, data on the vertical cross sections may be compared with theoretical expectations for the meridional height dependence of the quiet ionosphere. Several workers, (Hirono, 1955), and Martyn (1956), have investigated the equilibrium height (of hmax) for an ionosphere controlled by diffusion, height-varying electron loss rate, and uniform (or zero) vertical electron drift. The results are qualitatively in agreement with these observations in predicting a rise of hmax towards the equator in daytime and a reversal of this tendency at night.

The N(t) curves are perhaps the most physically significant representation of electron density data. The strong solar control at all levels and the important perturbations of this solar control in the upper F region may be easily seen.

Acknowledgments

We are indebted to Mr. A. H. Shapley for guidance in the initiation of this work, and to Dr. H. H. Howe for the development of the computer programs upon which the whole system heavily depends. This series of reports results from the combined efforts of the NBS Electron Density Profile Group, including at various times L. R. Wescott, L. Hayden, D. J. Brown, F. J. Burmont, I. Ford, N. Moore, M. Durham, G. Lira, under the direct supervision of G. H. Stonehocker. The cooperation of the U. S. Army Signal Radio Propagation Agency, in particular the assistance of Mr. F. H. Dickson (Chief), is gratefully acknowledged.

References

Budden, K. G., "A method for determining the variation of Electron Density with height (N(z) curves) from curves of equivalent height against frequency (h'(f) curves). Proc. Cambridge Conf. on the Physics of the Ionosphere, pp 332-339, September 1954, Pub. by the Physical Society (1955).

Martyn, D. F., "Processes controlling ionization distribution in the ionosphere," Aust. J. Phys, 9, pp 161-165, March 1956.

Hirono, M., "Effect of gravity and pressure gradient on vertical drift in the F2 region," Rpt. on Iono. Res. in Japan, 9, No. 2, p 95-104, (1955).

Smith, N., "The relation of Radio Skywave Transmission to Ionosphere measurements," Proc. IRE, 27, No. 5, pp 332-347, (1939).

Wright, J. W., "A model of the F region above hmaxF2," Journal of Geophysical Research, 65 185-191, January 1960.

AVERAGE ELECTRON DENSITY — KP BELOW 4.5

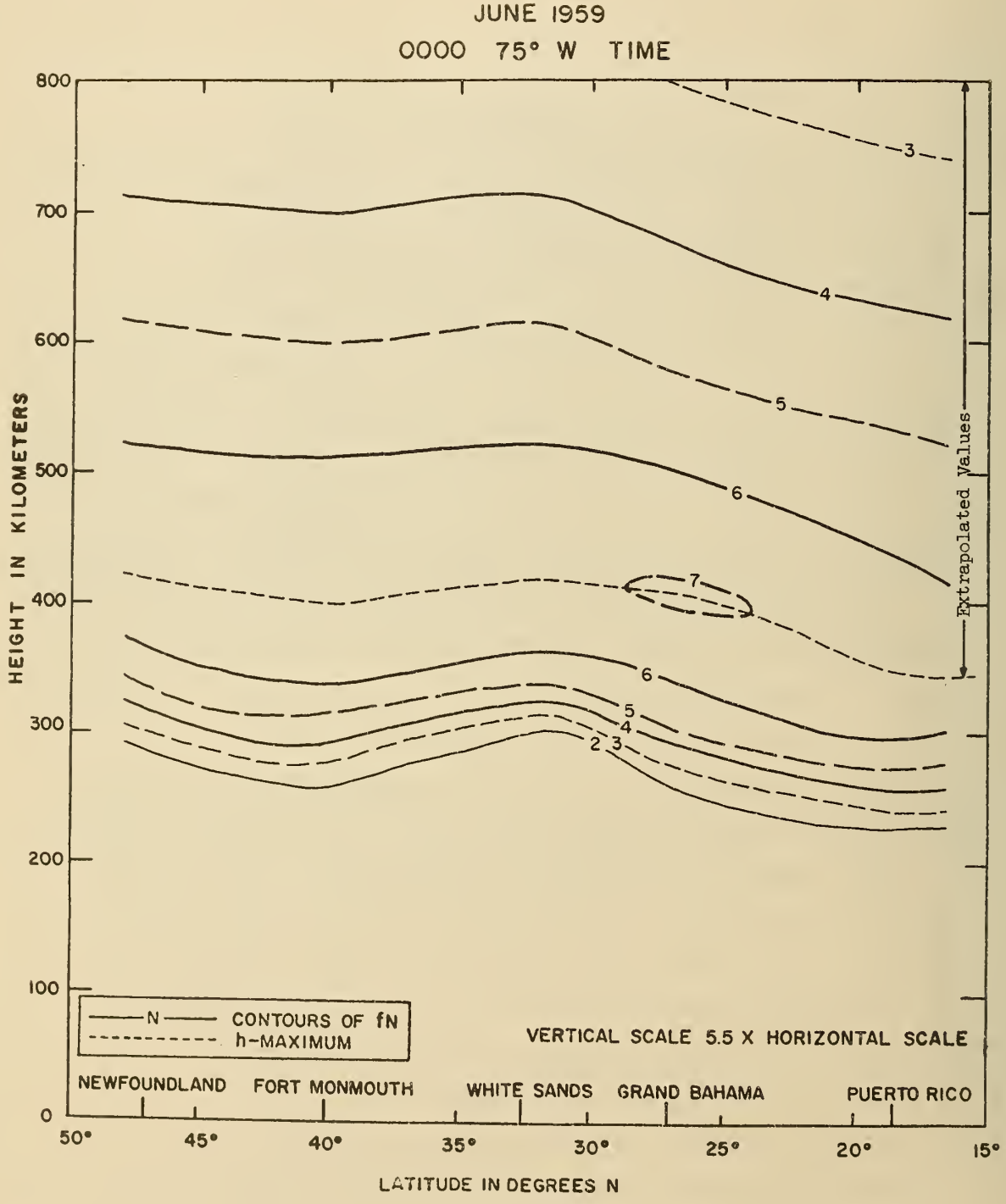
PUERTO RICO — 60 W — JUNE 1959

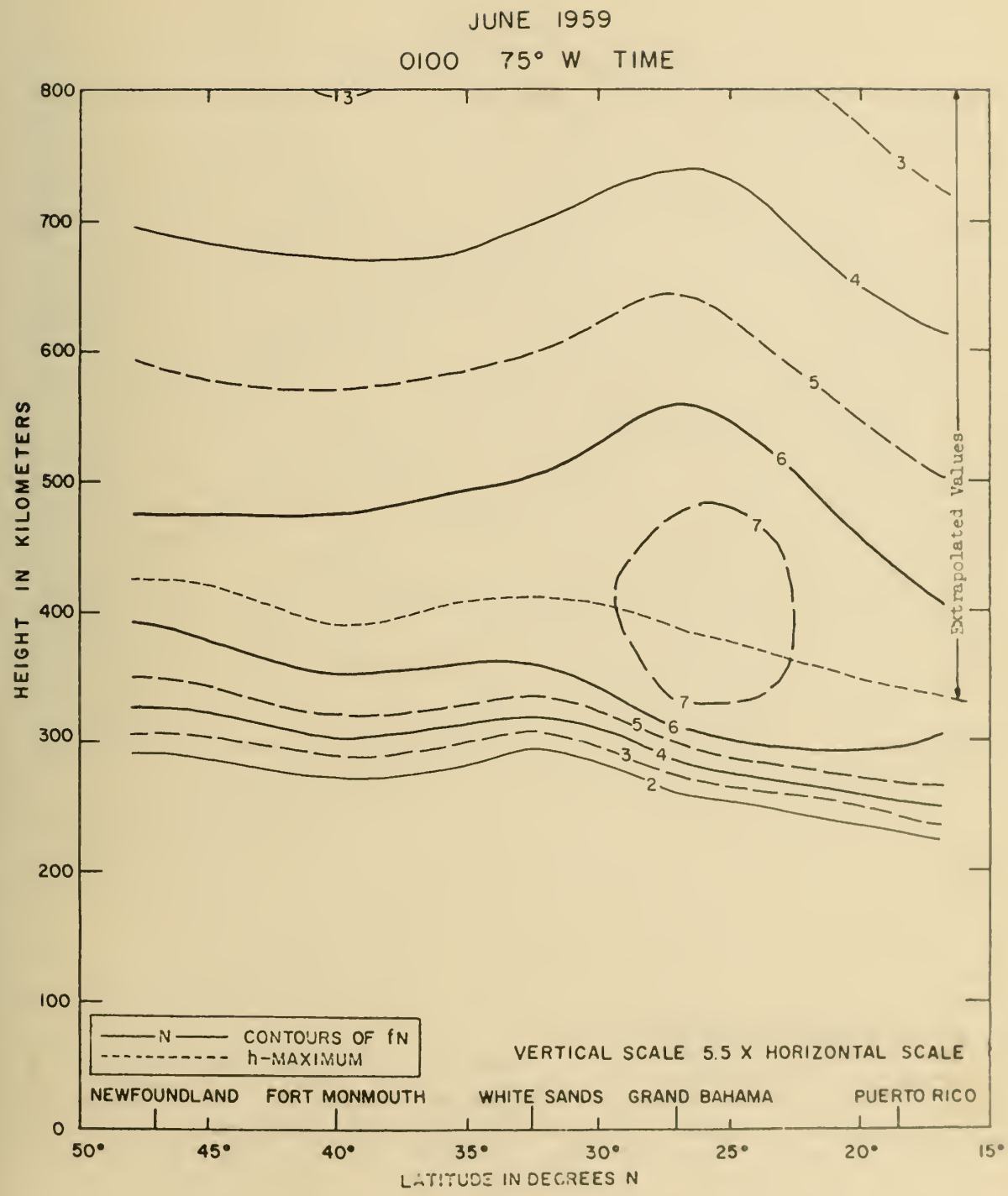
TIME	0000	0100	0200	0300	0400	0500	0600	0700	0800	0900	1000	1100
COUNT	27	29	28	27	25	21	23	16	19	19	17	15
HMIN	264	249	246	258	259	250	241	112	110	109	108	108
NMAX	1406	1232	990	915	862	793	795	889	1133	1247	1373	1482	
HMAX	371	354	367	377	372	365	352	312	335	345	363	368
SHMAX	901	808	718	666	583	556	564	836	1339	1559	1854	1992
SHINF	4868	4283	3511	3248	3016	2792	2308	3342	4533	5076	5728	6173
KM												
950	128	103	88.8	85.8	78.9	70.1	66.1	60.5	86.7	101	121	136
900	164	132	114	110	101	89.8	84.8	77.6	111	130	155	175
850	210	169	146	141	130	115	109	99.5	143	166	199	224
800	269	217	187	181	166	147	139	128	183	213	255	287
750	343	278	239	231	212	189	178	163	234	272	326	367
700	437	354	305	294	270	240	227	209	299	348	415	468
650	555	450	387	373	343	305	289	266	380	442	527	594
600	698	567	486	468	431	384	364	338	481	558	664	746
550	865	708	604	580	534	477	454	426	603	698	826	926
500	1052	866	734	701	646	580	555	530	745	858	1007	1123
490	1090	899	760	726	669	600	576	553	774	891	1044	1163
480	1127	932	786	750	692	621	597	576	805	925	1082	1203
470	1163	964	812	773	713	642	618	599	835	959	1118	1241
460	1199	996	837	795	734	662	638	623	865	992	1154	1279
450	1233	1028	861	816	754	681	656	647	896	1025	1188	1314
440	1265	1058	883	836	773	699	677	671	925	1056	1221	1348
430	1294	1087	904	854	790	716	696	694	954	1087	1252	1378
420	1321	1113	923	870	805	731	713	718	982	1115	1280	1406
410	1344	1138	940	882	817	744	728	741	1009	1143	1305	1429
400	1362	1159	953	890	826	755	742	763	1033	1168	1327	1448
390	1374	1177	962	921	893	851	776	784	1056	1189	1344	1461
380	1378	1190	966	916	890	852	784	804	1076	1207	1356	1468
370	1368	1195	962	904	879	847	789	823	1093	1221	1363	1468
360	1339	1192	950	880	857	834	788	839	1106	1230	1362	1457
350	1289	1180	924	843	822	812	781	853	1115	1233	1353	1434
340	1215	1153	884	791	774	780	768	864	1119	1228	1334	1398
330	1116	1110	829	726	711	738	745	871	1118	1215	1303	1349
320	991	1048	762	647	637	682	714	874	1109	1193	1262	1288
310	835	965	678	560	550	613	668	872	1092	1162	1209	1214
300	653	858	582	464	456	532	607	864	1066	1119	1145	1133
290	465	722	475	360	358	518	555	1101	1030	1121	1077	1045
280	290	570	362	261	305	407	455	1061	984	1053	1003	957
270	164	415	262	171	211	292	342	1003	928	977	922	867
260	85.3	256	179	100	142	175	236	928	861	898	831	782
250	42.6	128	106	41.1	94.5	81.3	134	837	786	815	757	702
240	23.5	50.5	54.8	12.2	61.5	26.0	84.9	732	702	733	677	631
230	5.7	18.7	25.9	3.2	30.0	8.8	63.2	621	615	655	605	572
220	1.4	4.2	8.3	.4	7.1	4.1	38.8	509	532	581	542	524
210			1.4			.3	24.1	414	456	513	492	484
200			.1				15.5	335	390	454	449	449
190							10.7	287	334	402	411	417
180							8.2	235	287	357	376	387
170							6.3	193	245	316	341	357
160							5.7	163	209	276	304	324
150							5.1	141	179	237	267	291
140							4.6	127	158	205	231	253
130							4.2	119	144	182	202	222
120							2.7	105	130	169	183	201
110								22.8	45.3	71.7	116	103

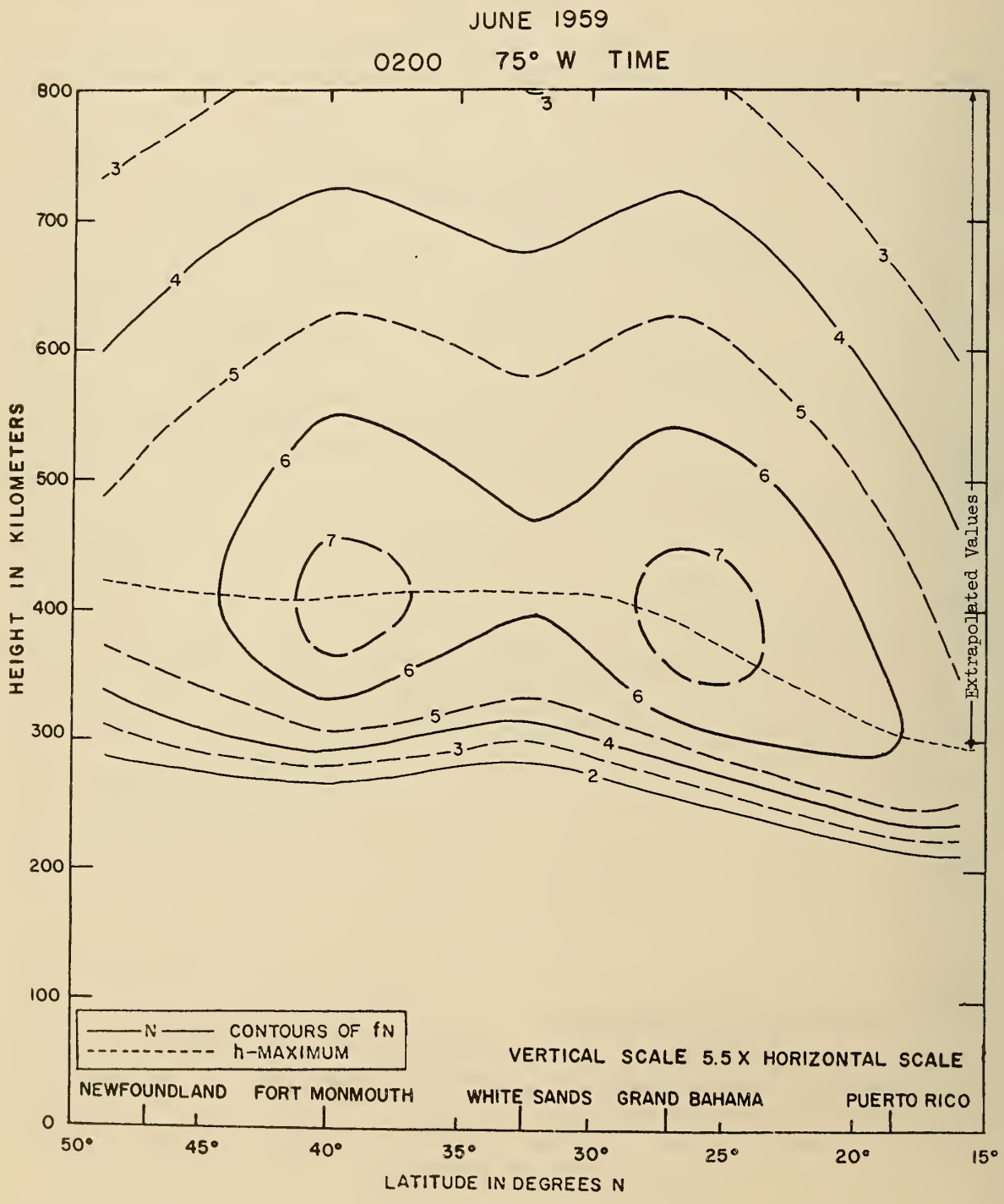
AVERAGE ELECTRON DENSITY — KP BELOW 4.5

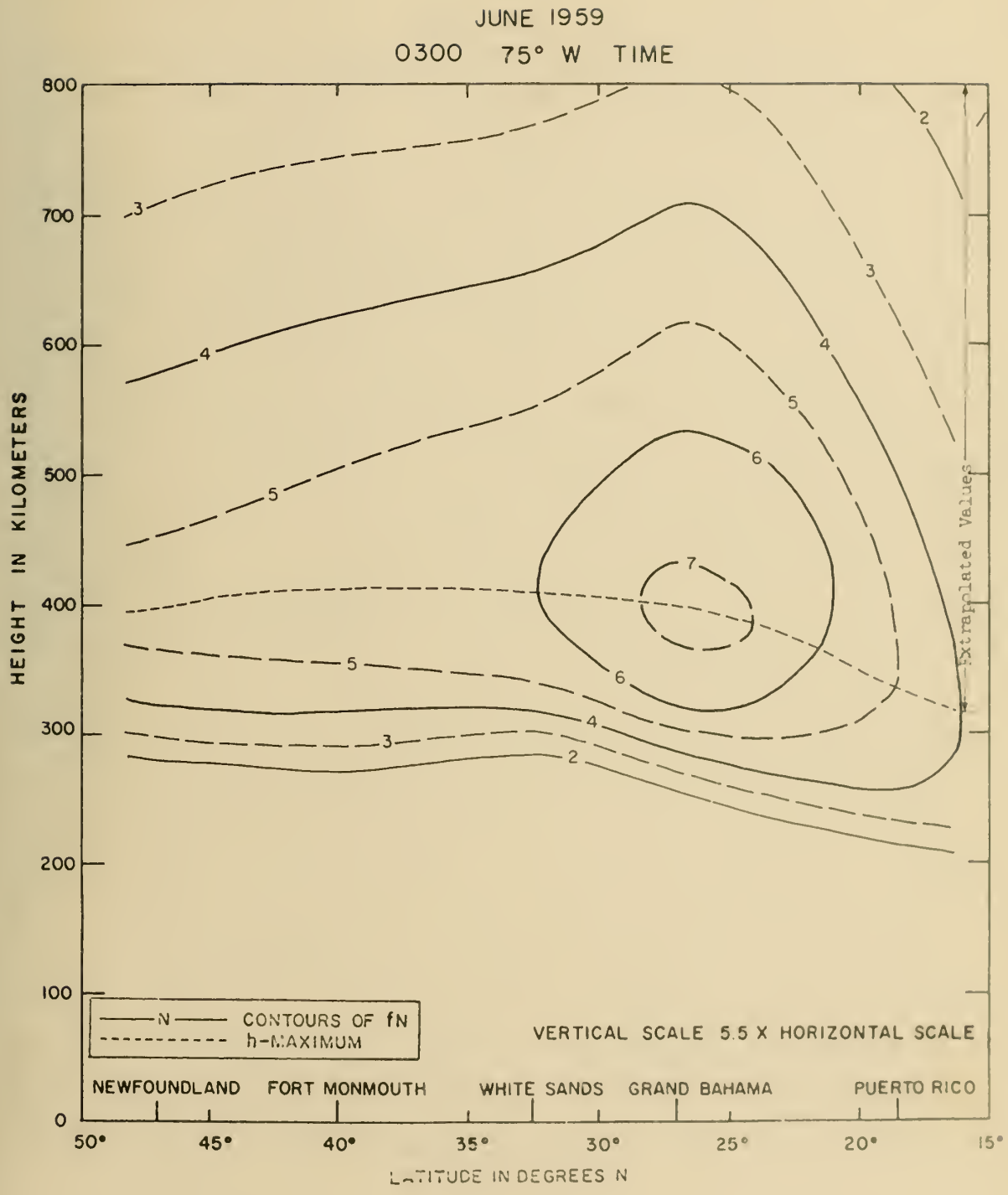
PUERTO RICO — 60 W — JUNE 1959

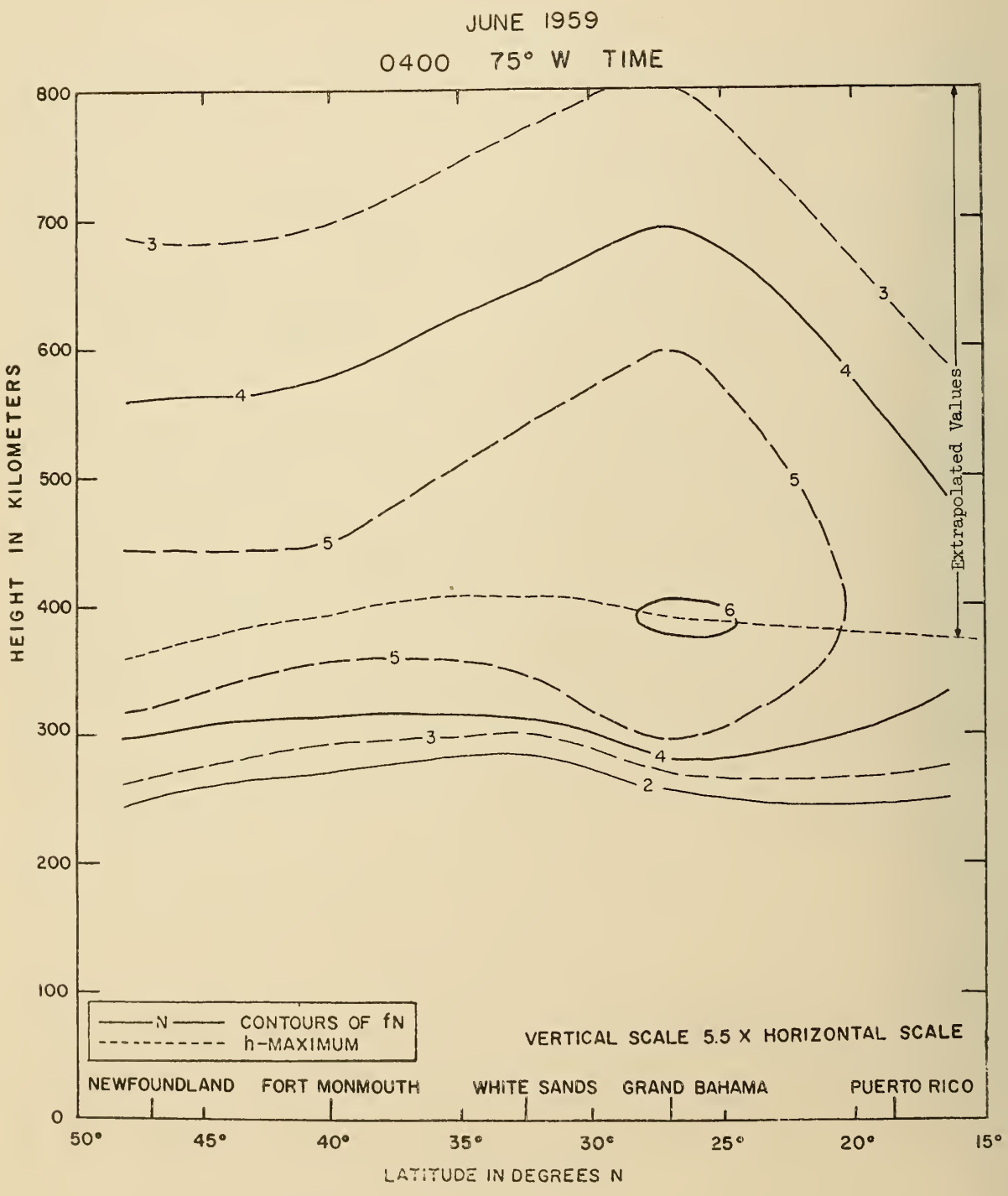
TIME	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
COUNT	18	20	20	18	18	17	8	18	19	22	25	28
HMIN	109	109	109	109	109	110	115	257	270	278	287	285
NMAX	1626	1741	1723	1756	1676	1548	1382	1331	1378	1432	1384	1404
HMAX	380	382	380	375	373	371	365	399	419	411	412	401
SHMAX	2167	2276	2205	2172	1971	1826	1522	1219	1225	1117	1044	992
SHINF	6753	7186	7065	7125	6558	6193	5421	4074	5113	5156	4948	4953
KM												
950	155	167	166	164	150	131	124	106	151	113	156	148
900	198	215	213	211	193	168	159	136	193	145	199	190
850	254	275	273	270	247	215	204	175	247	186	256	244
800	326	352	349	346	316	276	261	223	316	238	327	311
750	416	450	446	442	404	353	334	285	403	303	416	398
700	530	573	567	563	515	450	425	363	511	385	528	505
650	671	726	719	713	653	571	540	495	644	484	666	638
600	843	911	902	897	822	718	680	618	847	602	829	796
550	1043	1128	1115	1112	1020	893	845	759	1030	811	1011	977
540	1086	1174	1161	1158	1062	930	881	788	1067	841	1048	1014
530	1129	1221	1206	1205	1106	969	918	818	1104	870	1085	1052
520	1173	1268	1253	1252	1149	1007	955	847	1140	899	1122	1089
510	1217	1315	1299	1300	1193	1047	992	876	1175	976	1158	1127
500	1261	1363	1345	1347	1238	1086	1029	905	1209	1005	1193	1163
490	1305	1409	1391	1395	1282	1125	1067	932	1241	1033	1226	1198
480	1347	1455	1436	1441	1325	1164	1104	959	1271	1059	1257	1232
470	1389	1500	1479	1487	1368	1203	1140	984	1297	1083	1285	1264
460	1429	1543	1521	1531	1409	1240	1176	1007	1321	1104	1311	1293
450	1466	1583	1560	1573	1448	1276	1211	1028	1340	1121	1332	1320
440	1501	1620	1596	1612	1485	1310	1243	1047	1355	1136	1350	1342
430	1533	1654	1628	1648	1519	1342	1274	1134	1364	1210	1361	1359
420	1560	1682	1656	1679	1550	1370	1301	1151	1365	1288	1364	1369
410	1583	1706	1677	1705	1576	1395	1326	1158	1355	1283	1357	1372
400	1600	1723	1693	1726	1596	1515	1346	1319	1333	1396	1338	1364
390	1610	1734	1701	1740	1611	1531	1361	1395	1543	1531	1302	1342
380	1613	1735	1701	1746	1618	1540	1372	1373	1481	1458	1244	1304
370	1605	1724	1690	1740	1616	1541	1375	1335	1395	1361	1161	1247
360	1584	1698	1664	1721	1601	1531	1369	1280	1285	1240	1056	1164
350	1549	1655	1623	1685	1571	1507	1352	1209	1161	1009	929	1058
340	1498	1592	1565	1632	1522	1465	1319	1125	1021	935	784	930
330	1434	1514	1491	1559	1457	1408	1272	1029	865	755	623	779
320	1358	1421	1401	1470	1375	1338	1212	919	700	568	456	616
310	1270	1319	1299	1366	1279	1254	1139	794	523	384	298	442
300	1176	1207	1187	1251	1171	1155	1053	658	357	220	165	277
290	1072	1092	1069	1130	1054	1049	1218	503	219	110	75.5	147
280	968	975	950	1004	933	936	1090	347	108	31.5	28.8	52.9
270	868	862	834	878	815	818	955	198	43.7	9.3	6.6	10.0
260	774	759	732	760	705	704	815	97.5	15.3	3.0		
250	688	670	643	659	611	599	680	35.4	5.0	2.0		
240	617	599	570	576	537	512	557	10.9		1.3		
230	558	542	515	513	478	443	457	1.4		.4		
220	512	501	474	466	432	389	379					
210	474	469	442	430	397	348	318					
200	443	443	417	402	366	314	271					
190	415	419	394	377	339	282	232					
180	388	394	371	352	312	252	198					
170	360	362	347	326	283	222	170					
160	330	332	318	297	255	192	147					
150	294	297	283	263	224	167	128					
140	255	259	247	229	194	147	116					
130	227	229	220	204	175	136	108					
120	205	206	202	190	163	126	88.9					
110	106	72.0	91.0	93.5	66.1	38.8	3.1					

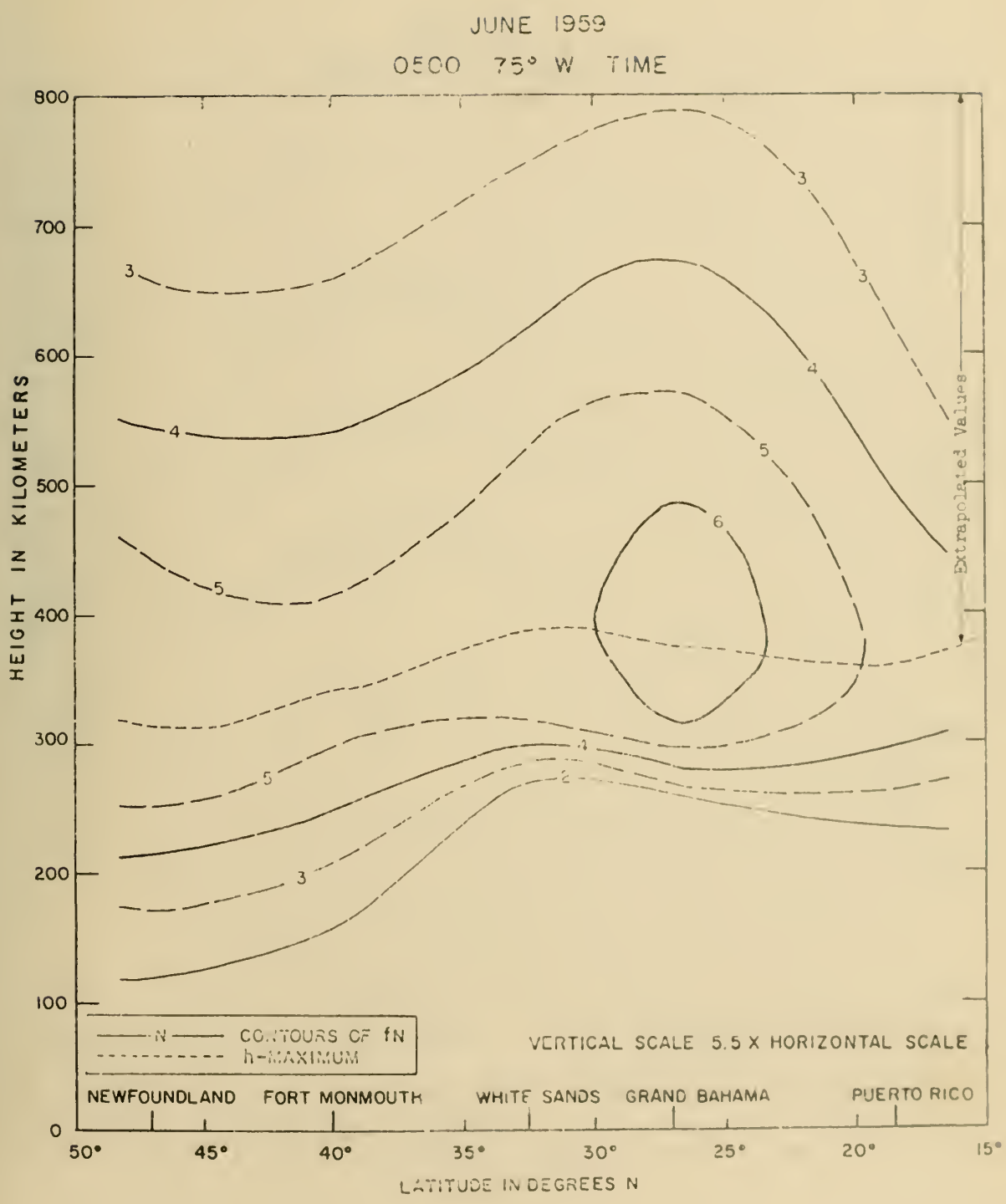

JUNE 1959
0000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
4
5
6
7
6
5
4
3
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

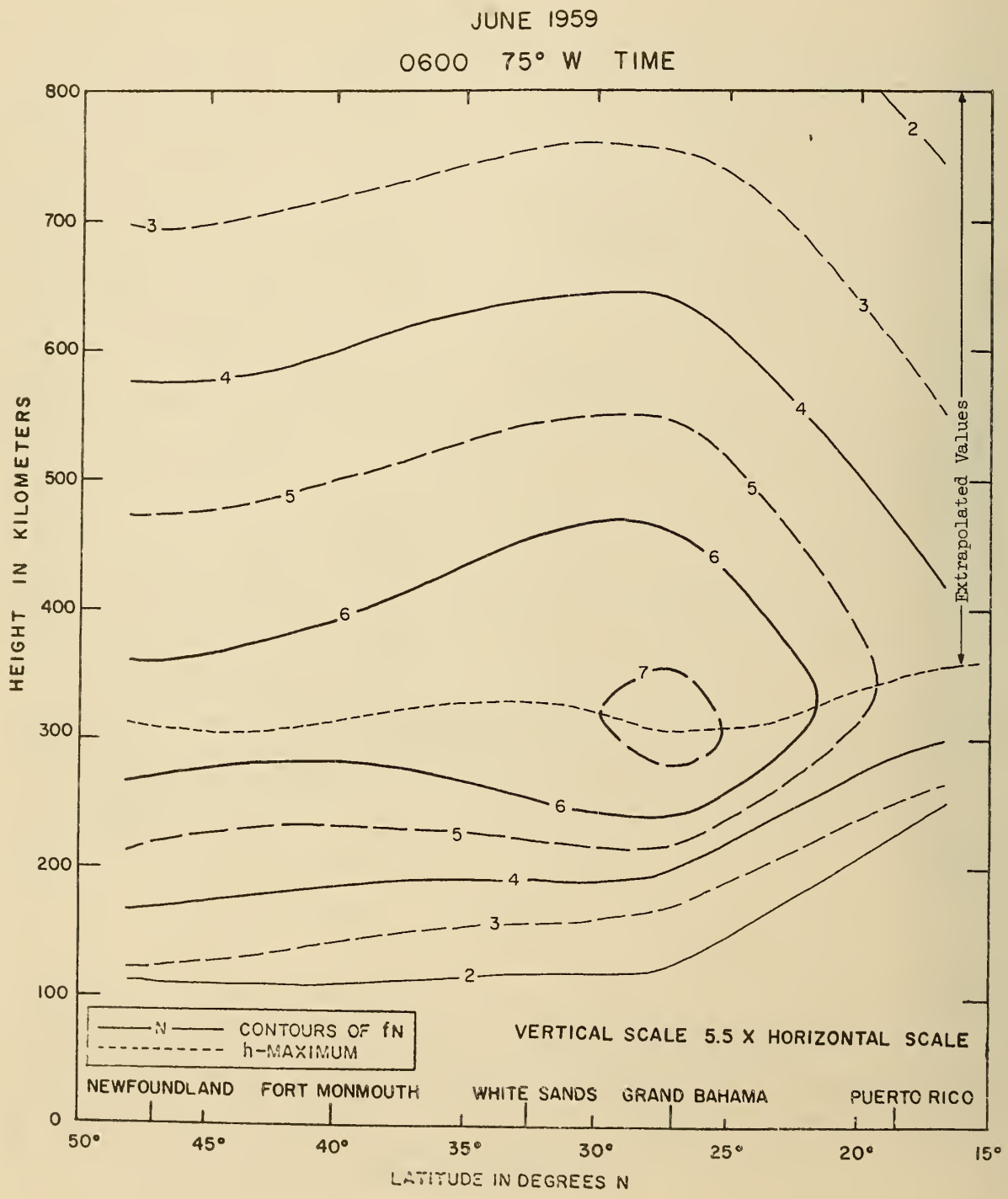

JUNE 1959
0100 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
13
3
4
5
6
7
7
5
6
3
4
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

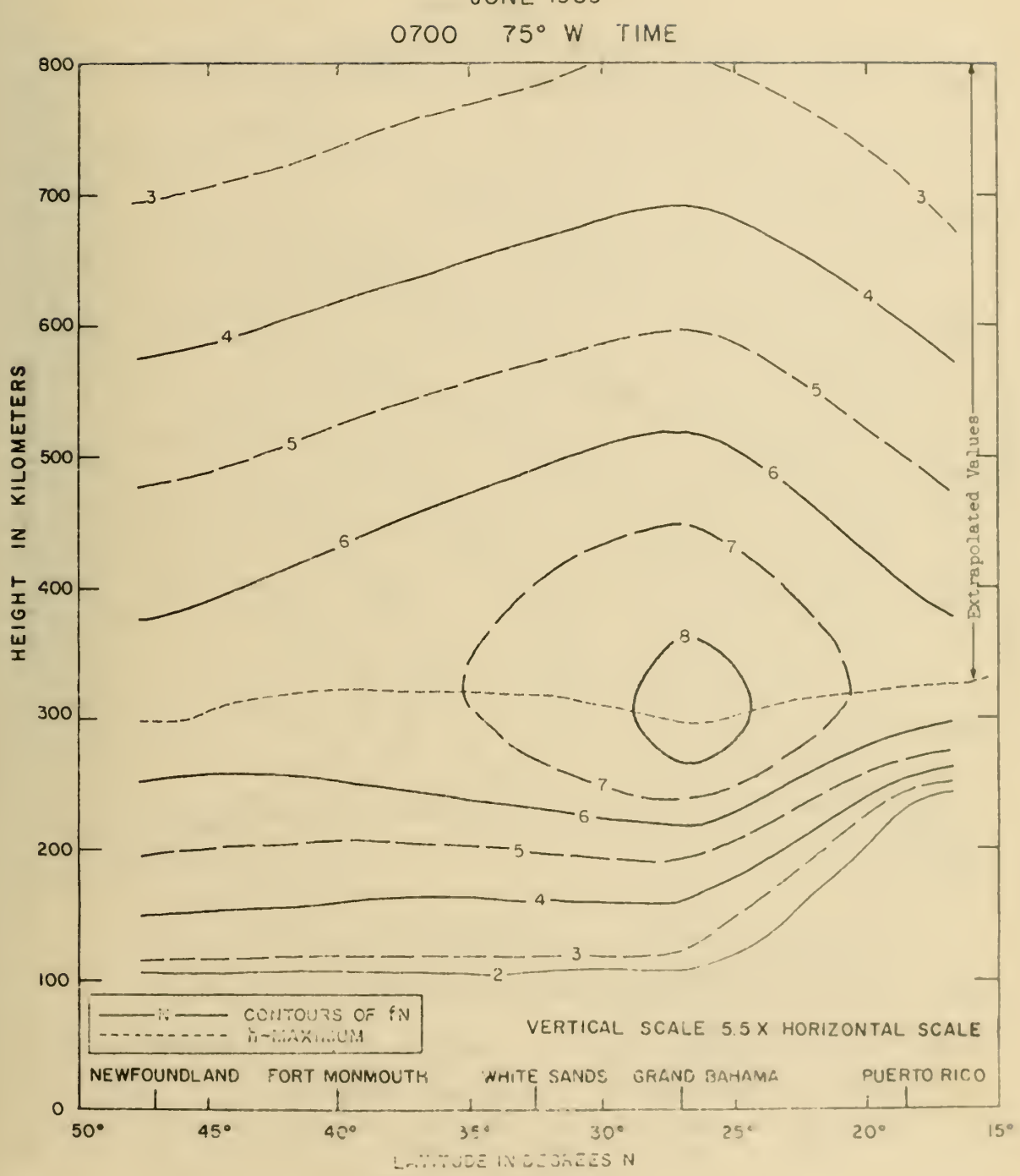

JUNE 1959
0200 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N


JUNE 1959
0300 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO


JUNE 1959
0400 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
4
5
6
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

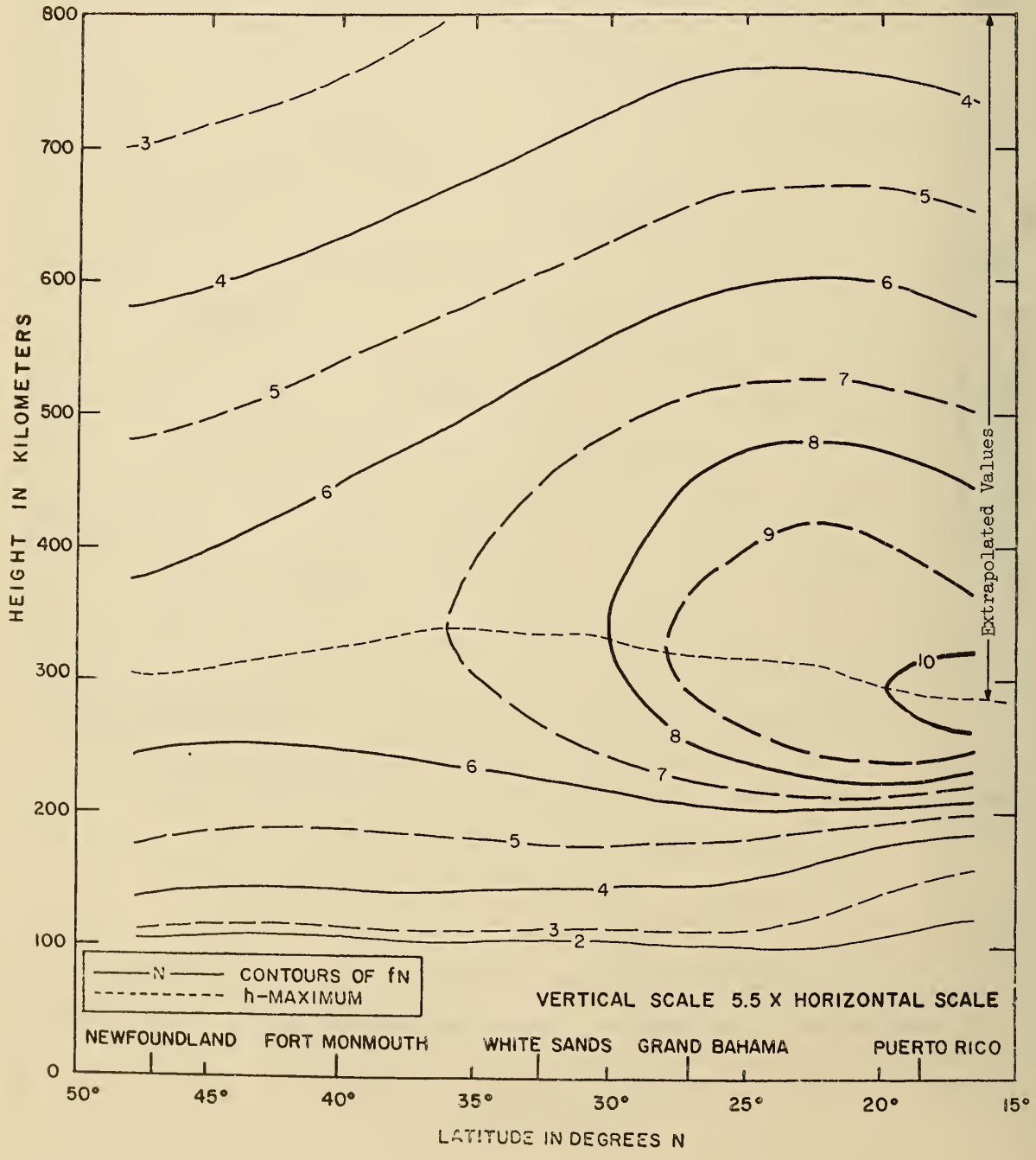

JUNE 1959
0500 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
4
5
6
Extrapolated Values
N CONTOURS OF fN
h=MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

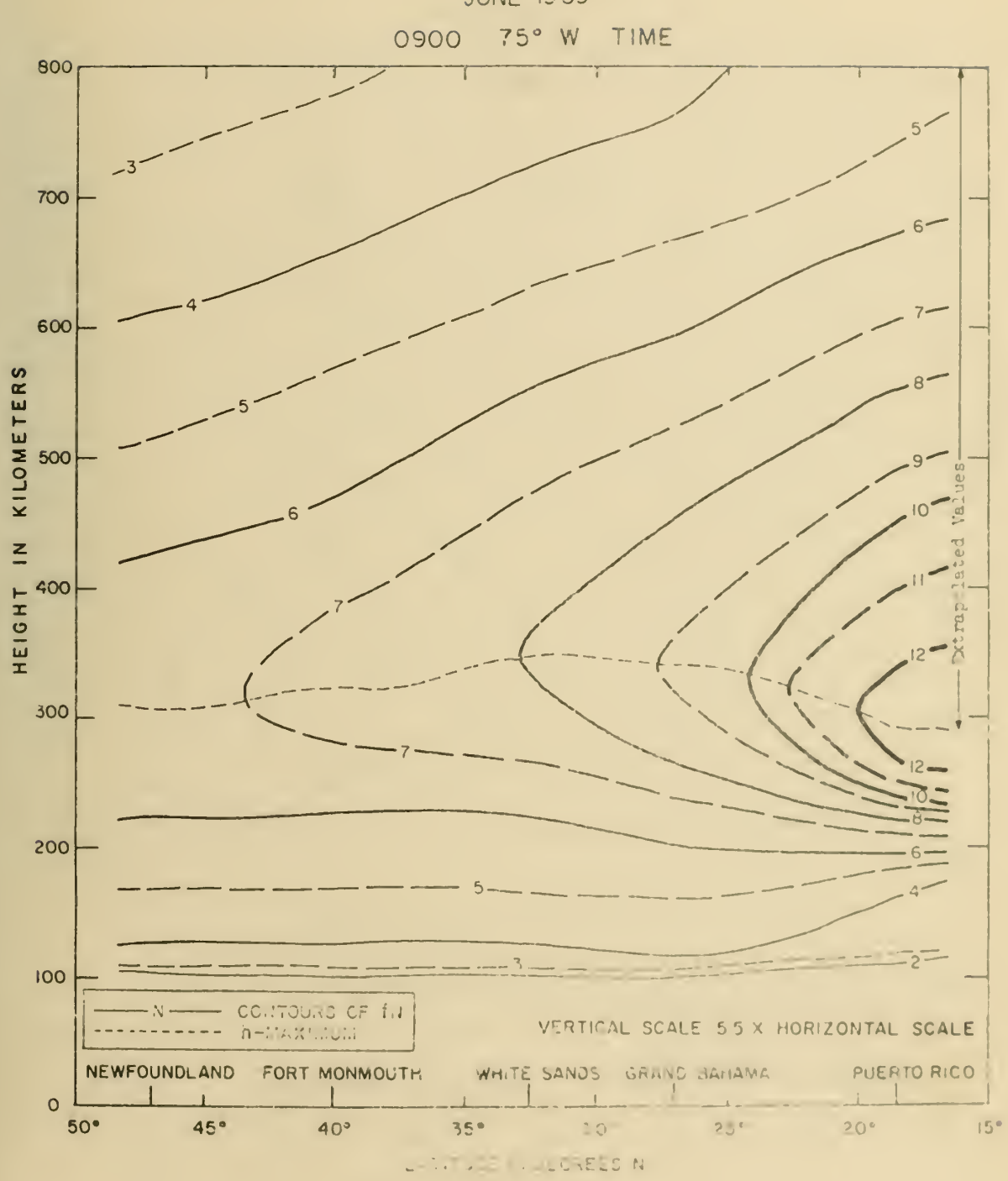

JUNE 1959
0600 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

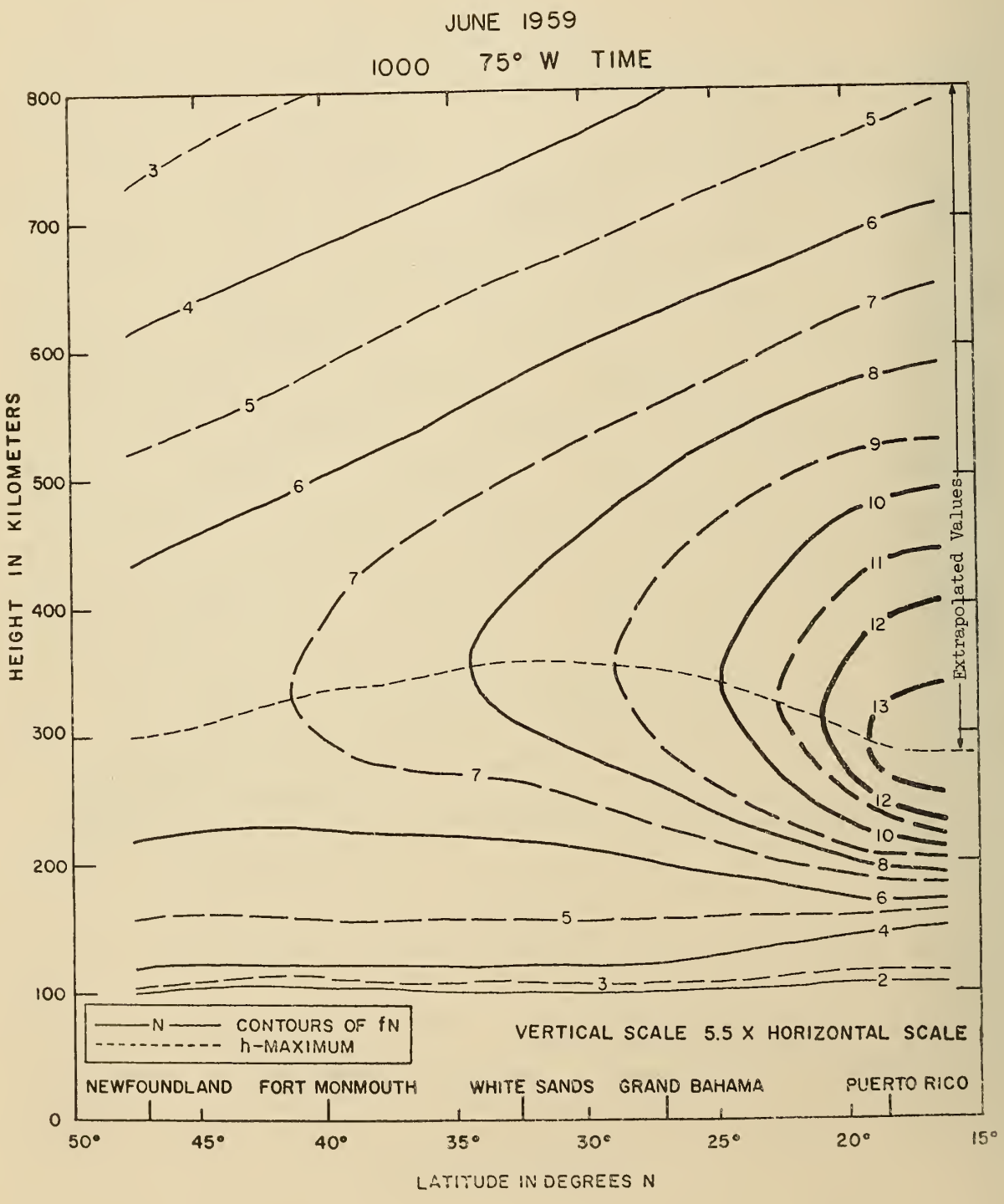

JUNE 1959
0700 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

JUNE 1959

0800 75° W TIME

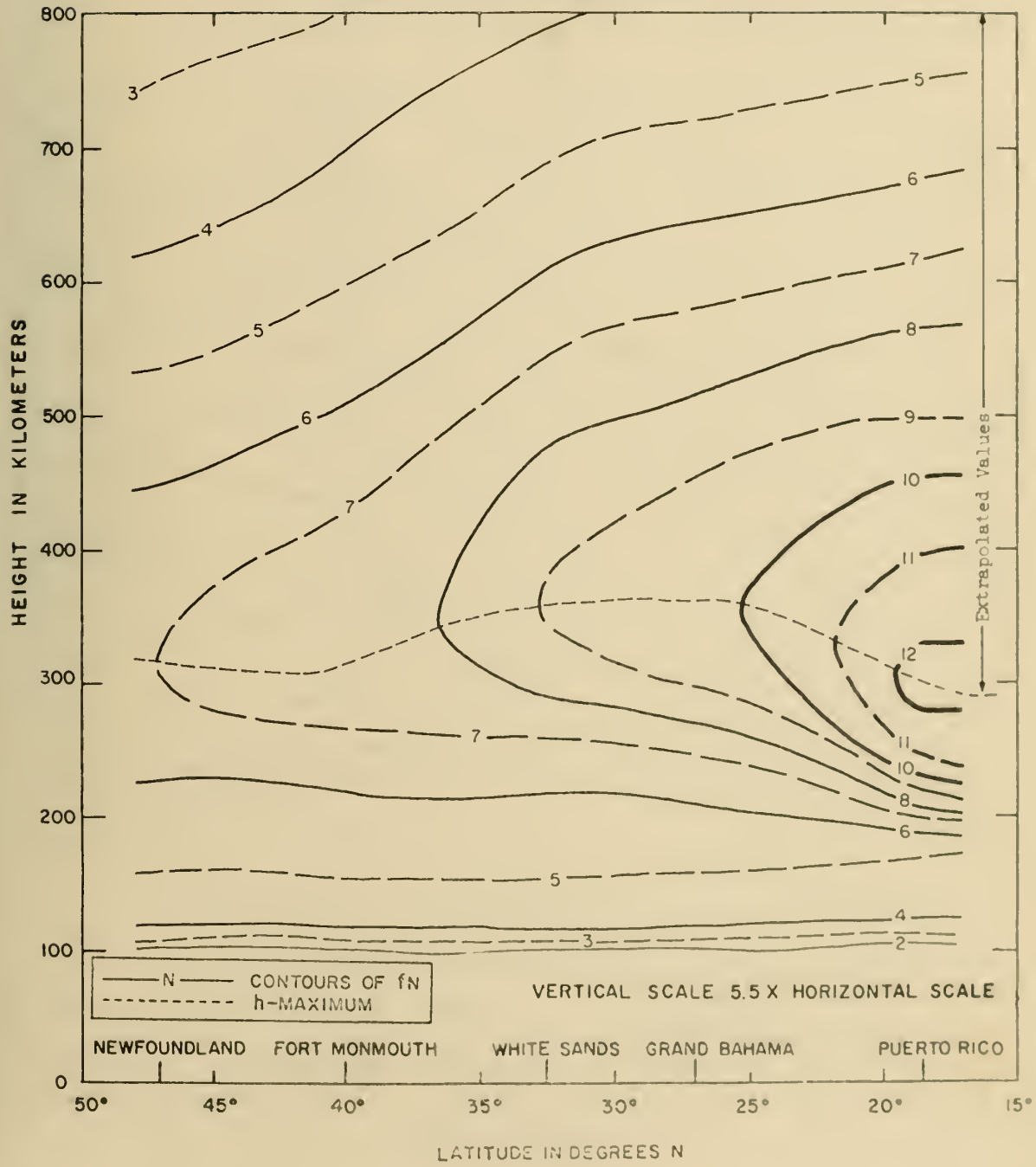


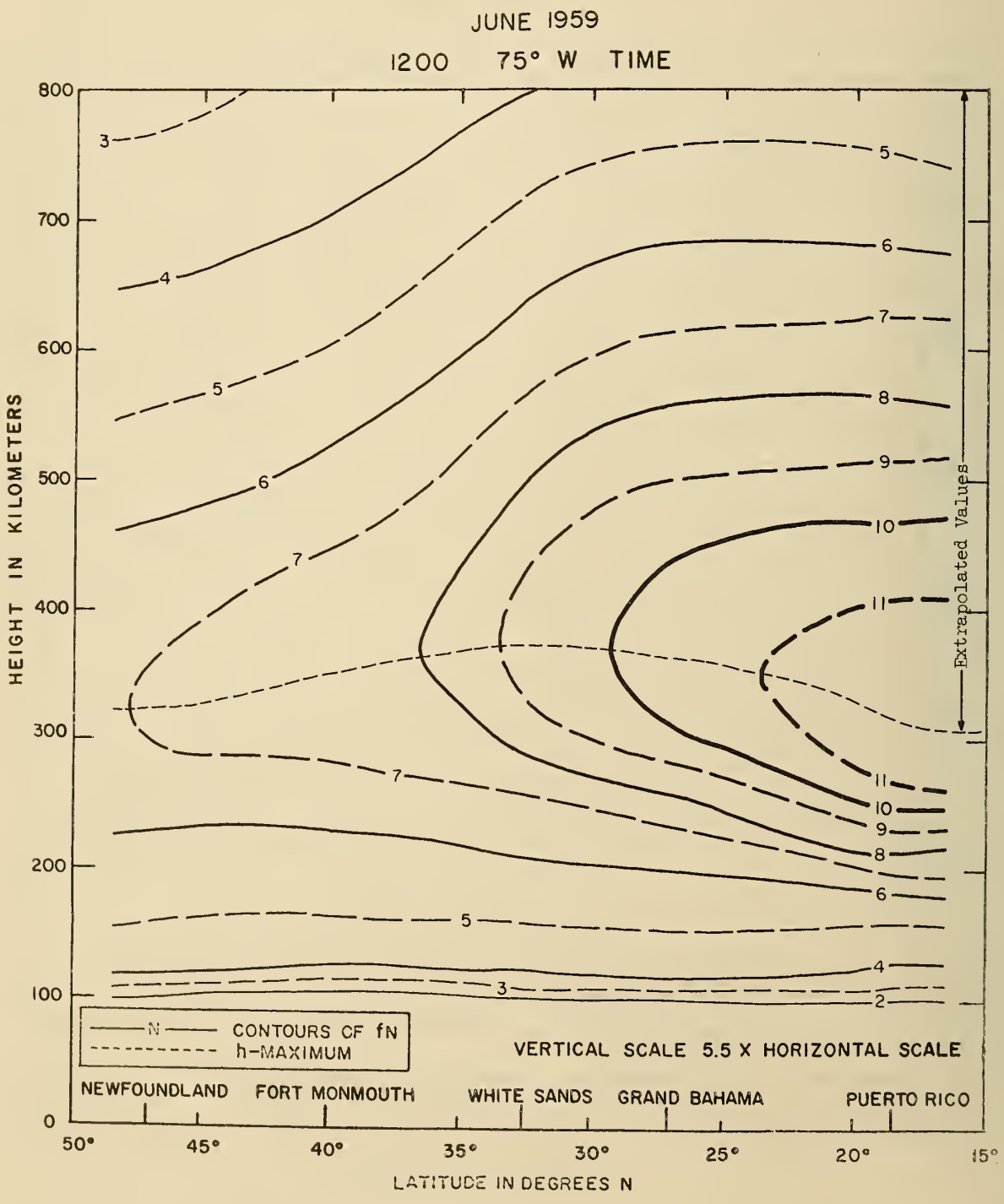

JUNE 1959
0900 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
4
5
6
7
8
9
10
11
12
Extrapolated Values
N —— CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE DEGREES N


JUNE 1959
1000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

JUNE 1959

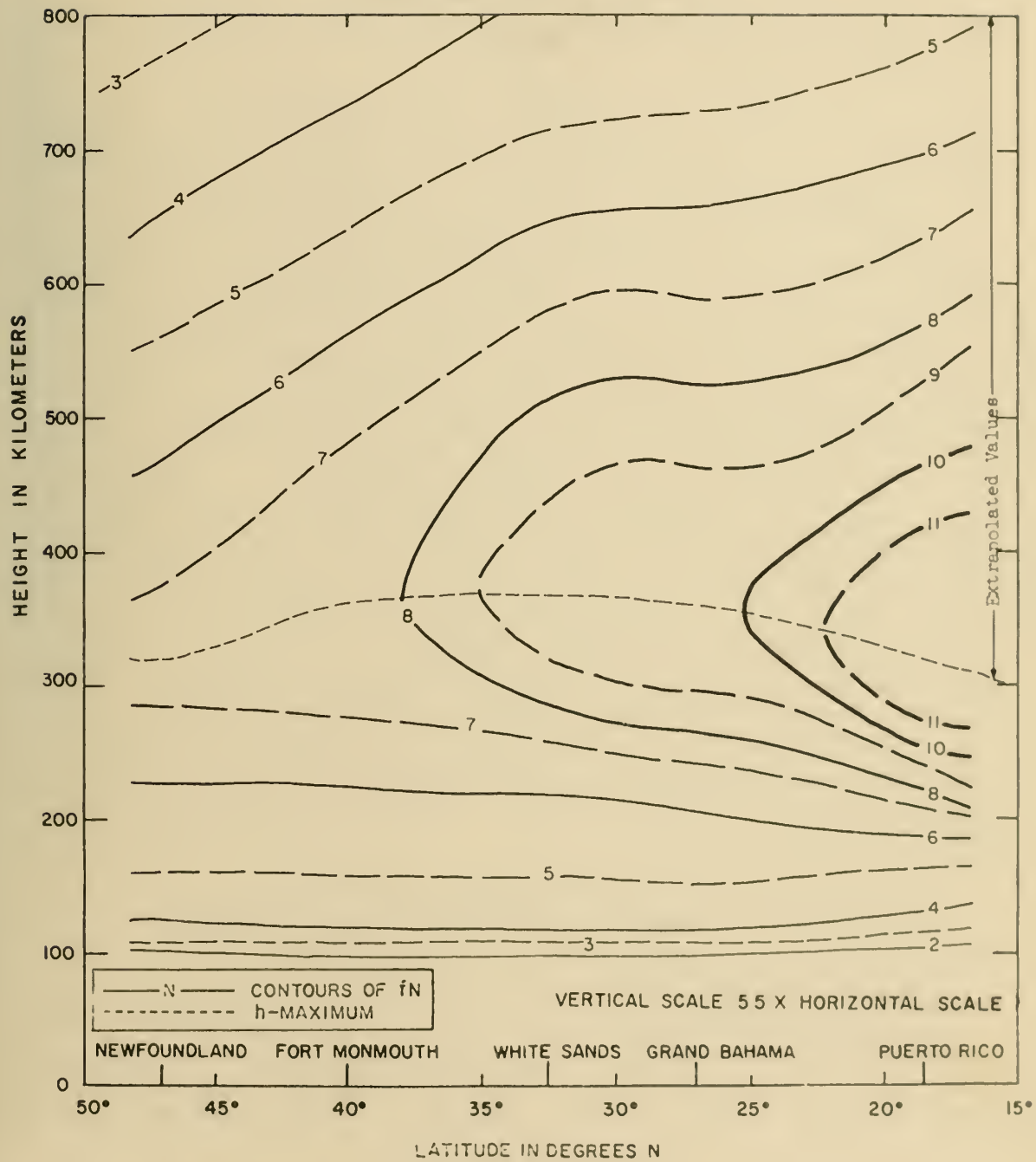
1100 75° W TIME




JUNE 1959
1200 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
3
4
5
6
7
8
9
10
11
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

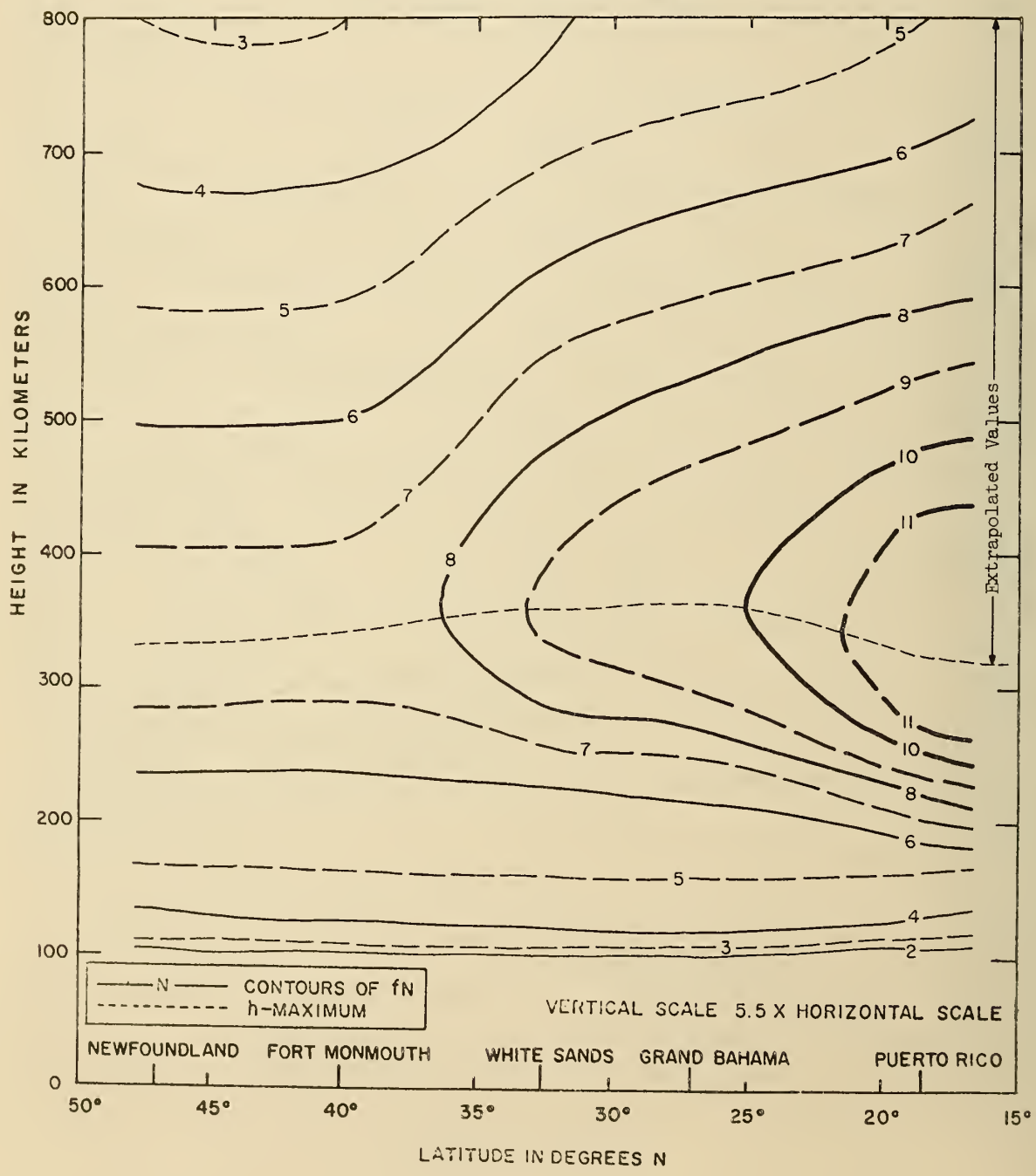
JUNE 1959

1300 75° W TIME



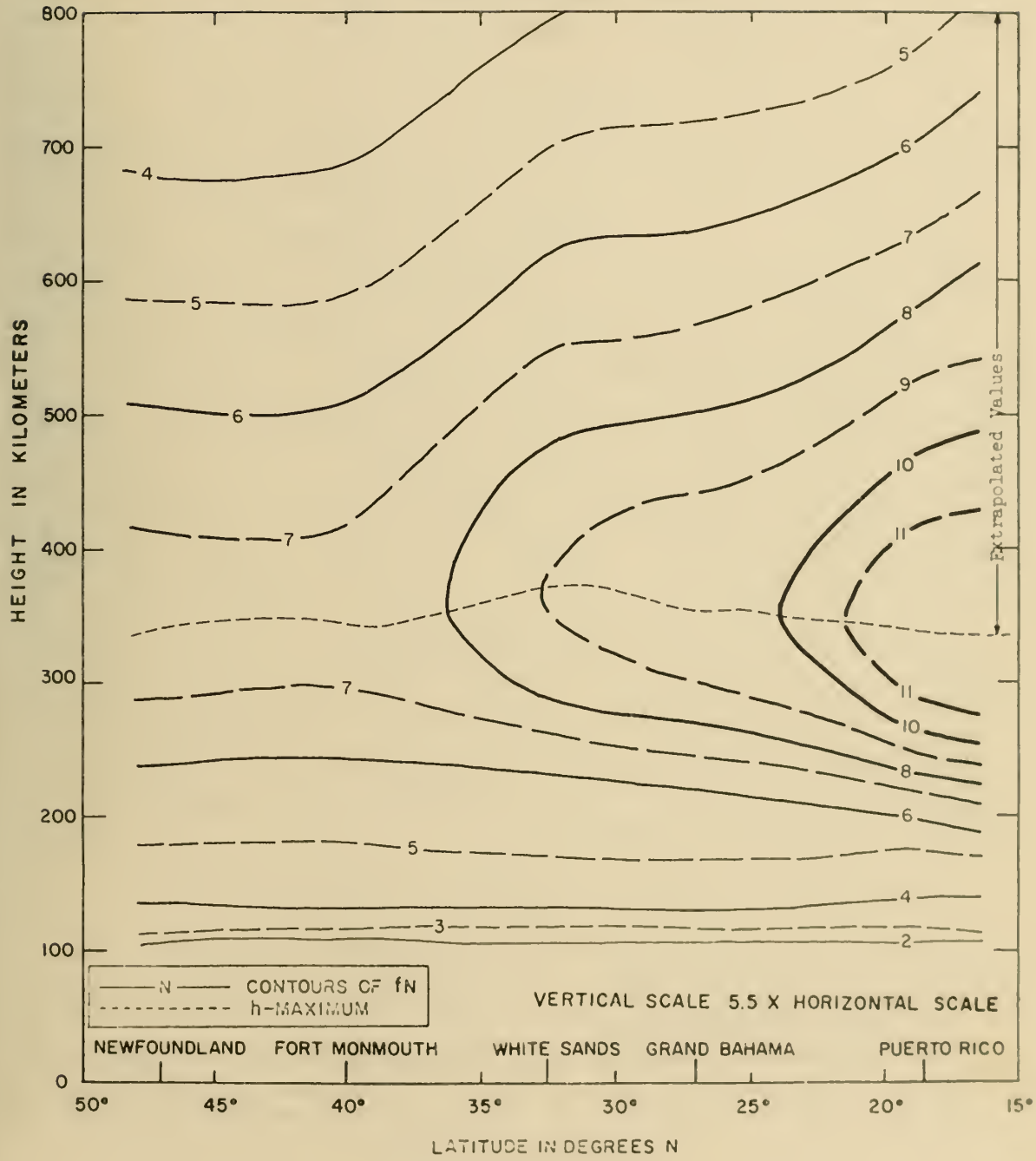
JUNE 1959

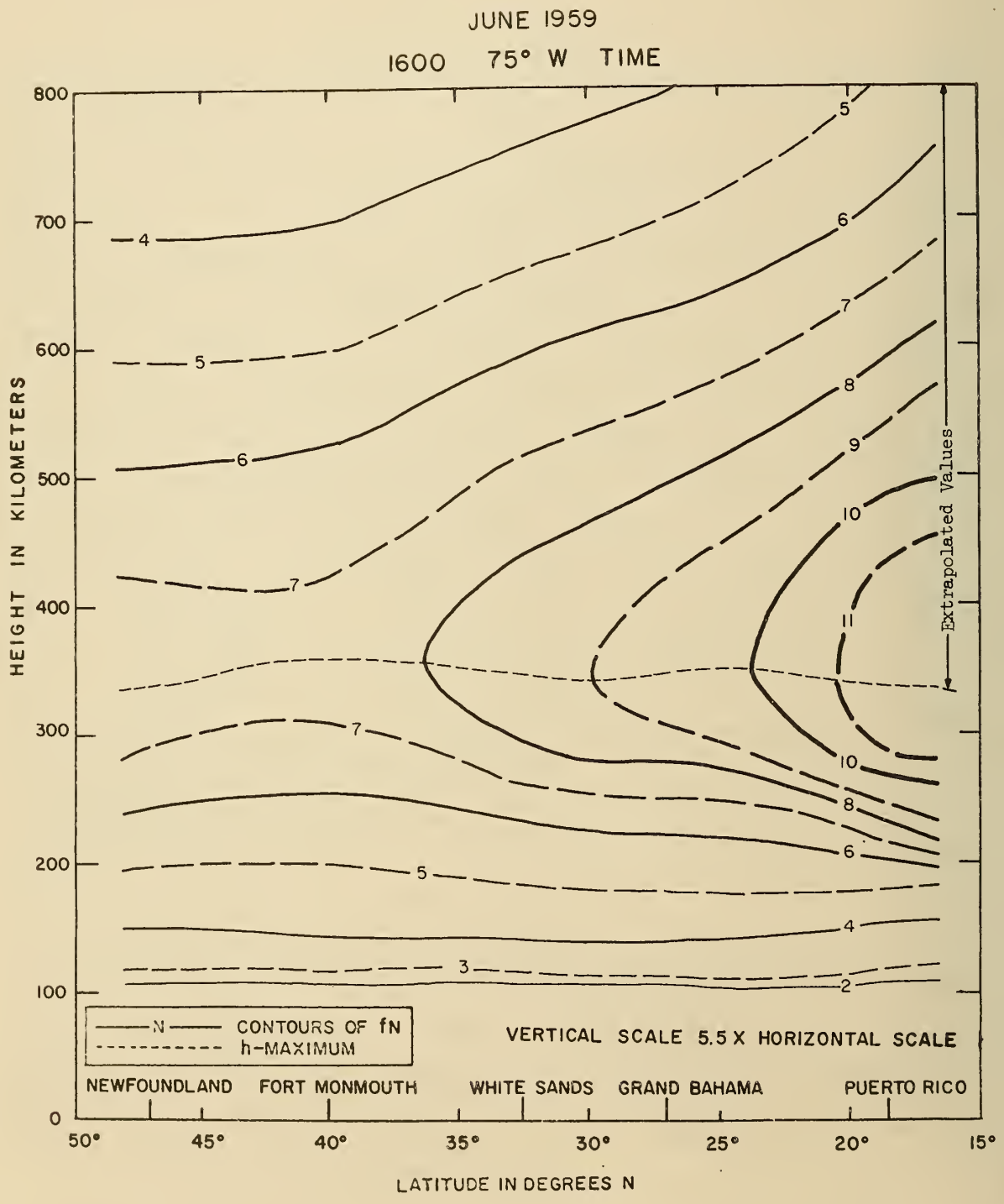
1400 75° W TIME



JUNE 1959

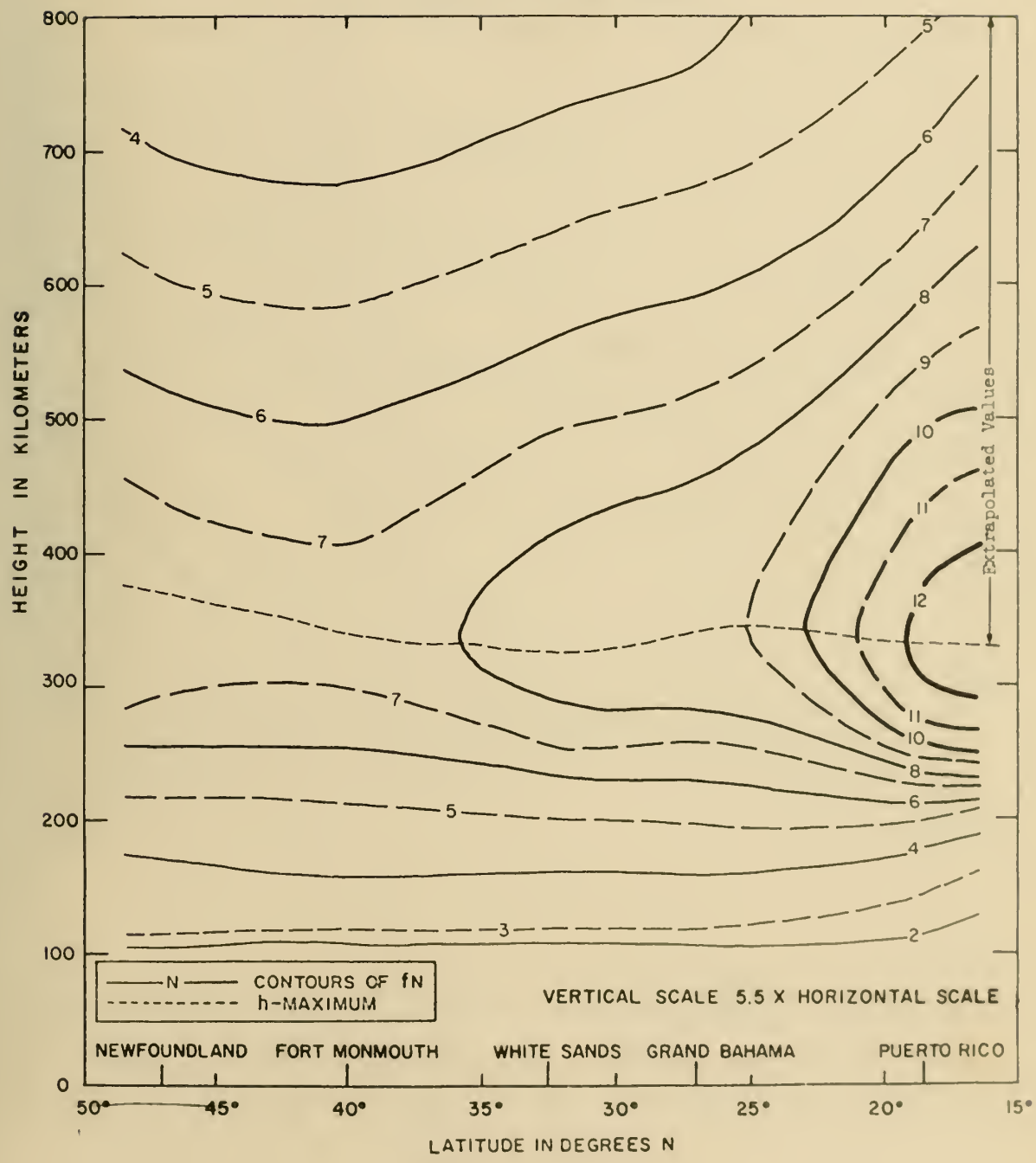
1500 75° W TIME

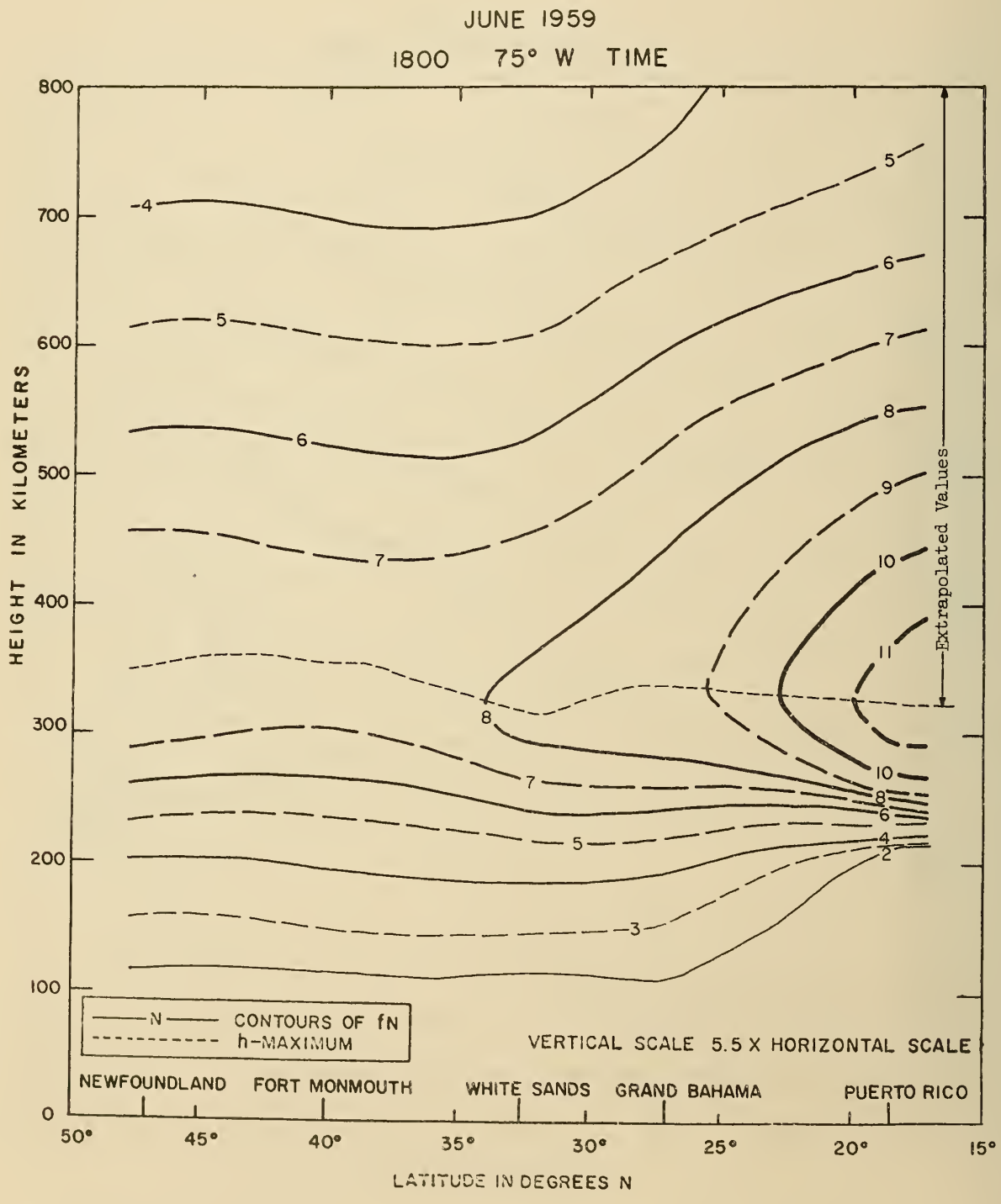


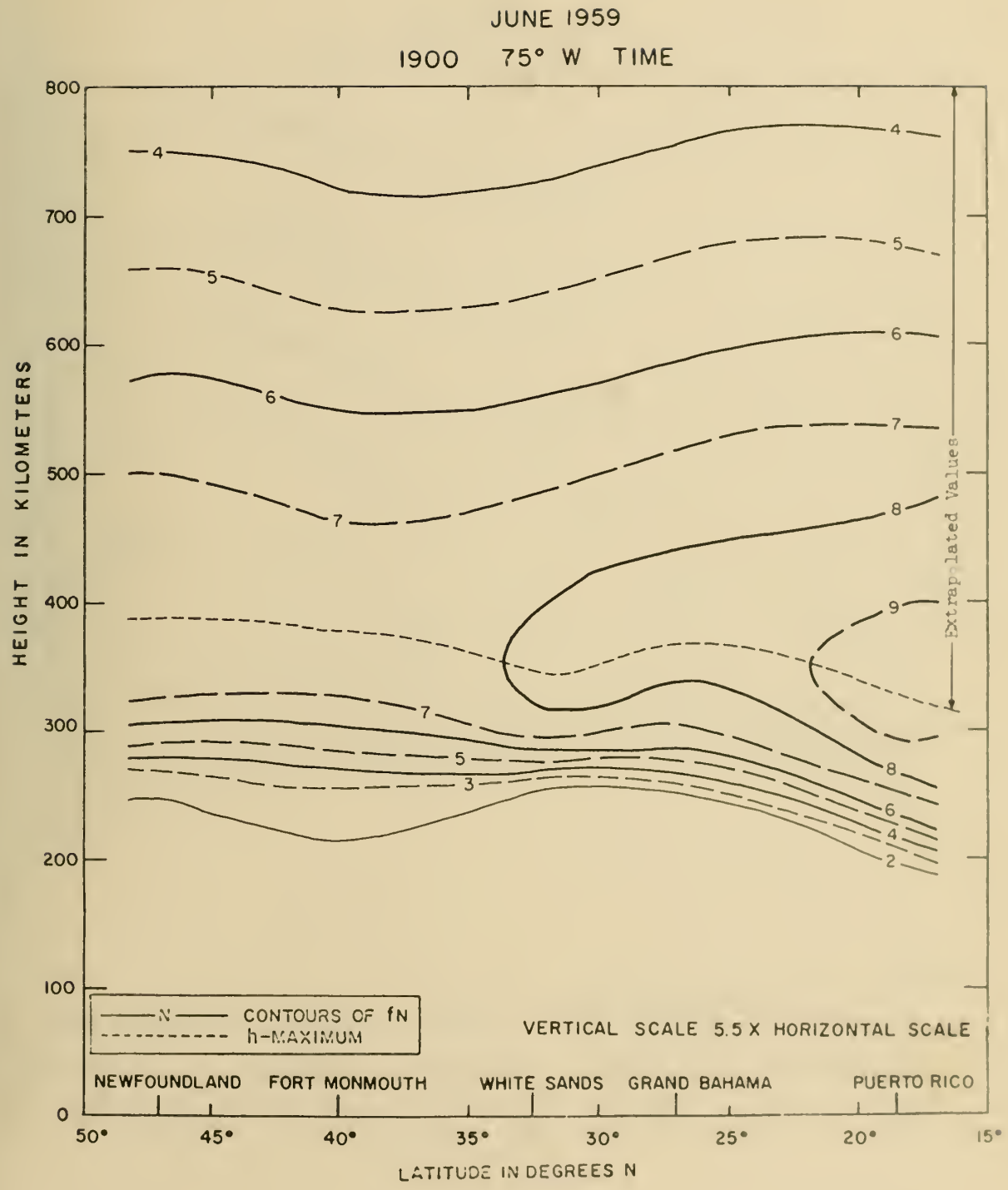

JUNE 1959
1600 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
6
7
8
9
10
11
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

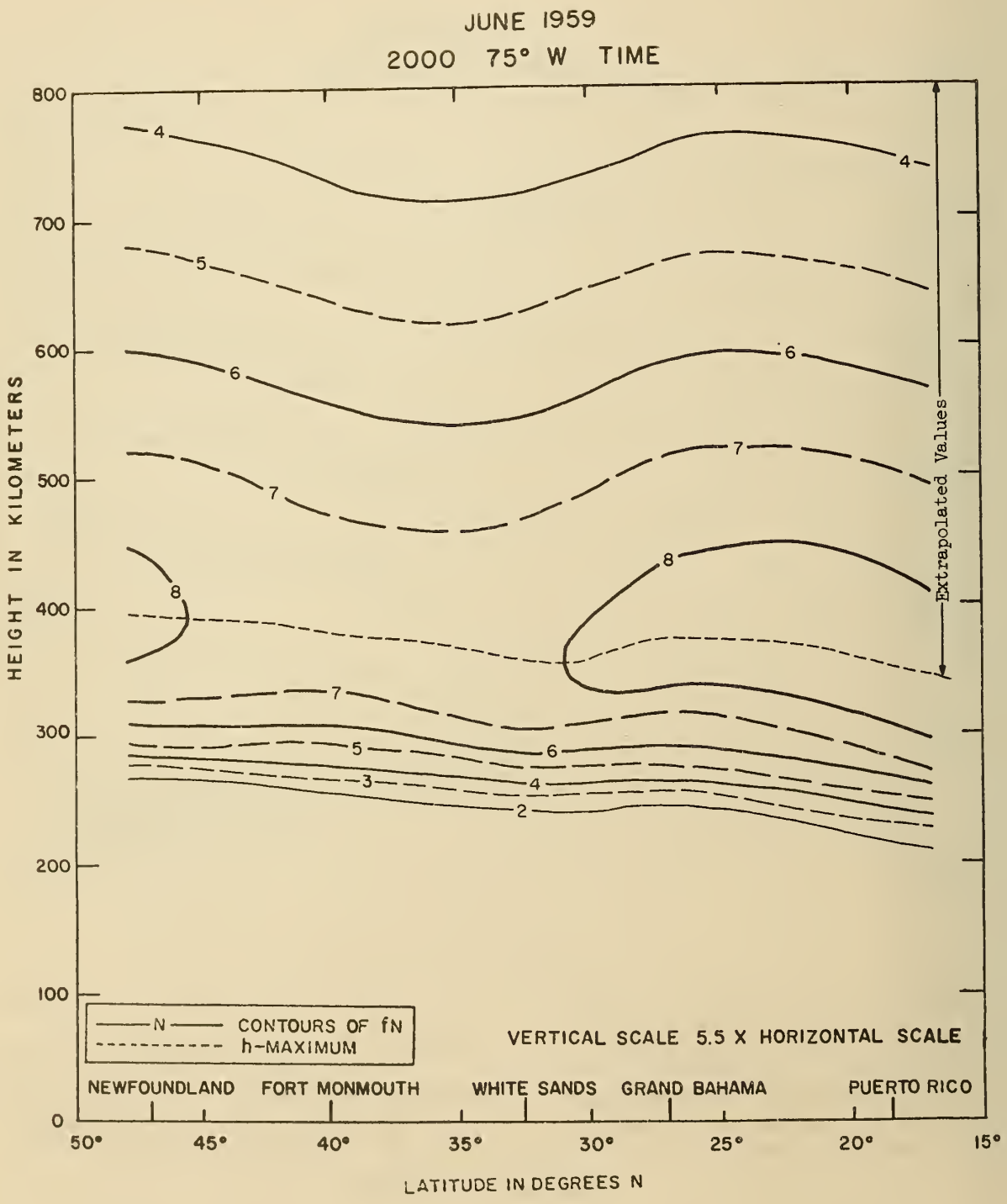
JUNE 1959

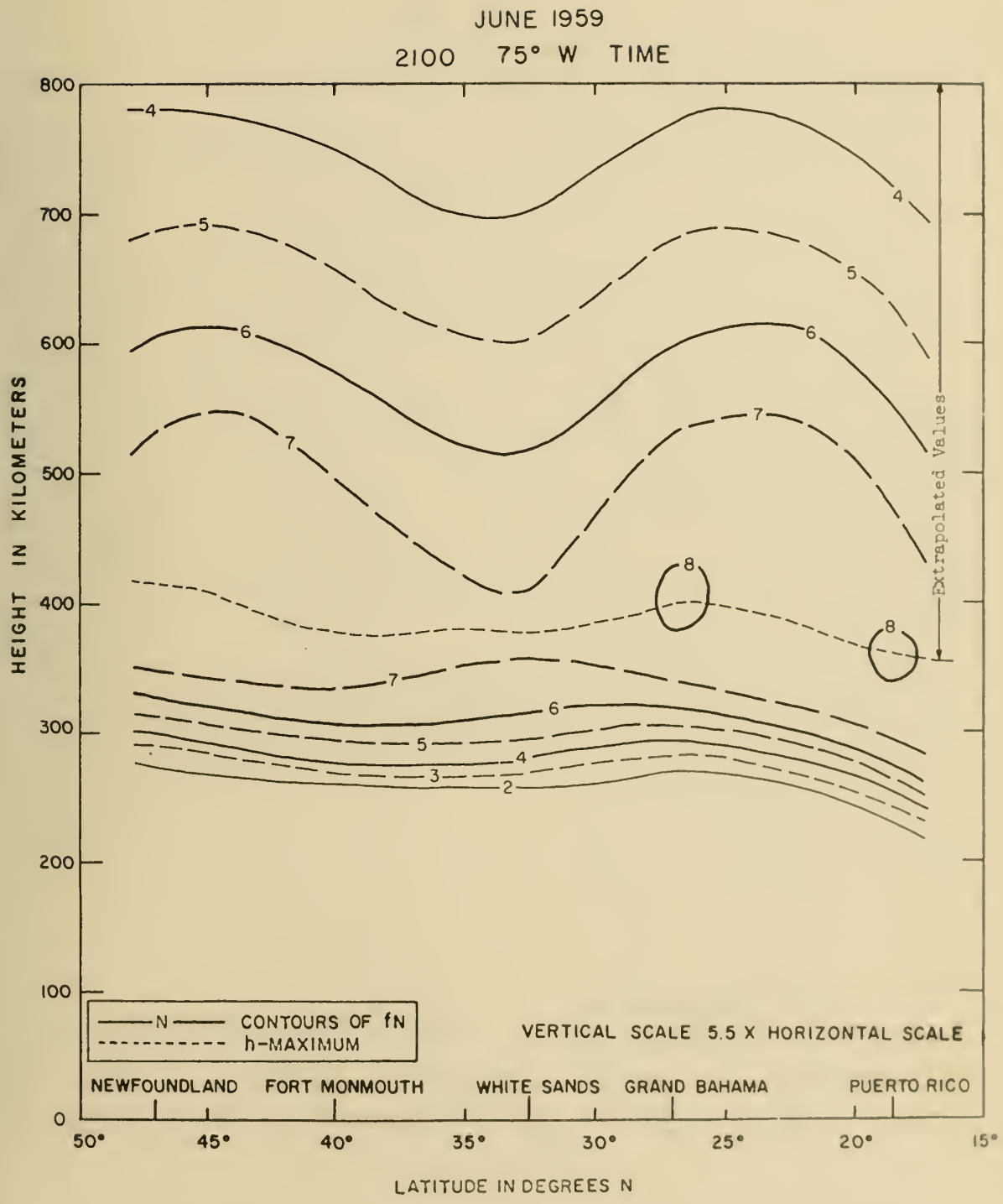
1700 75° W TIME

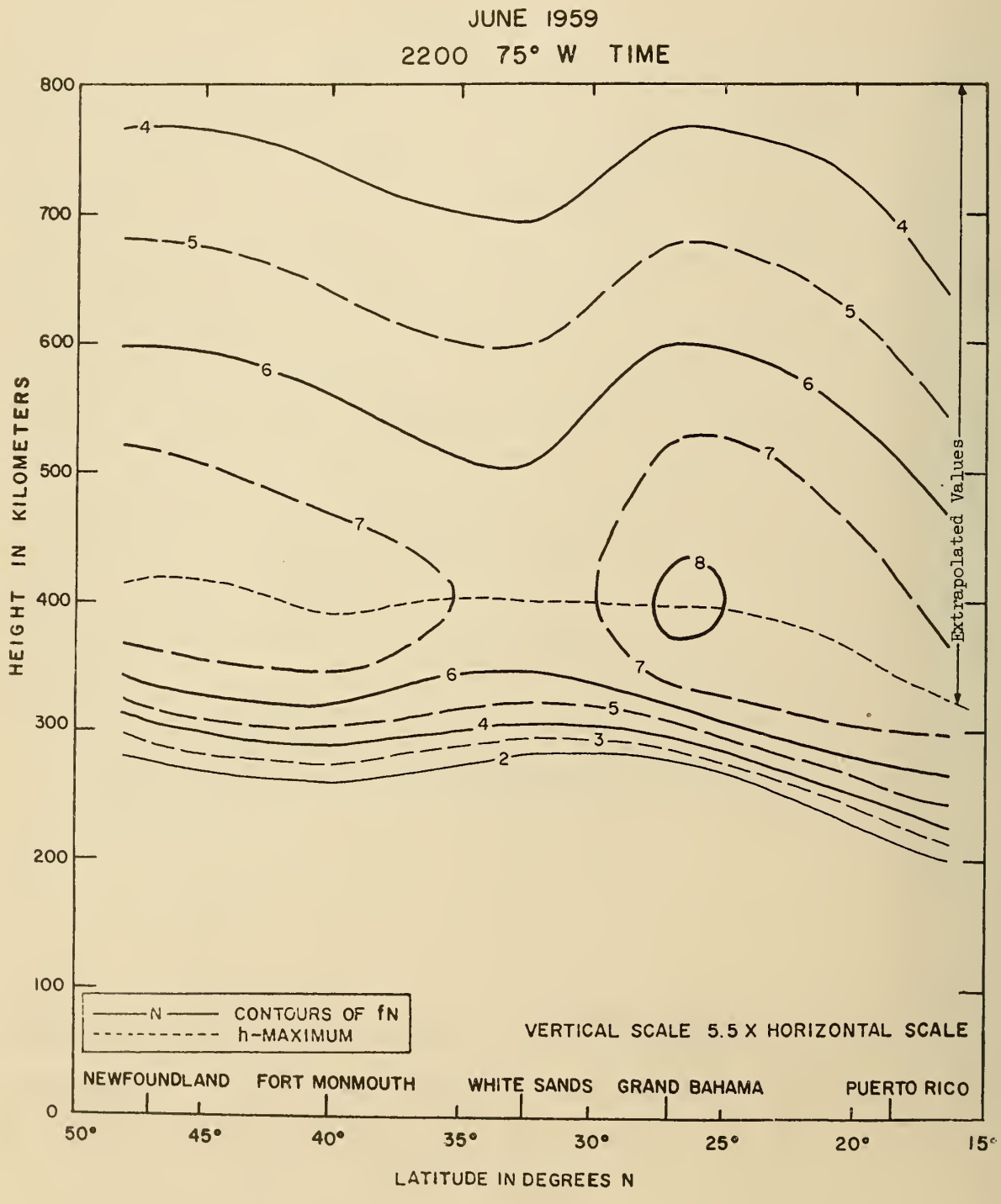


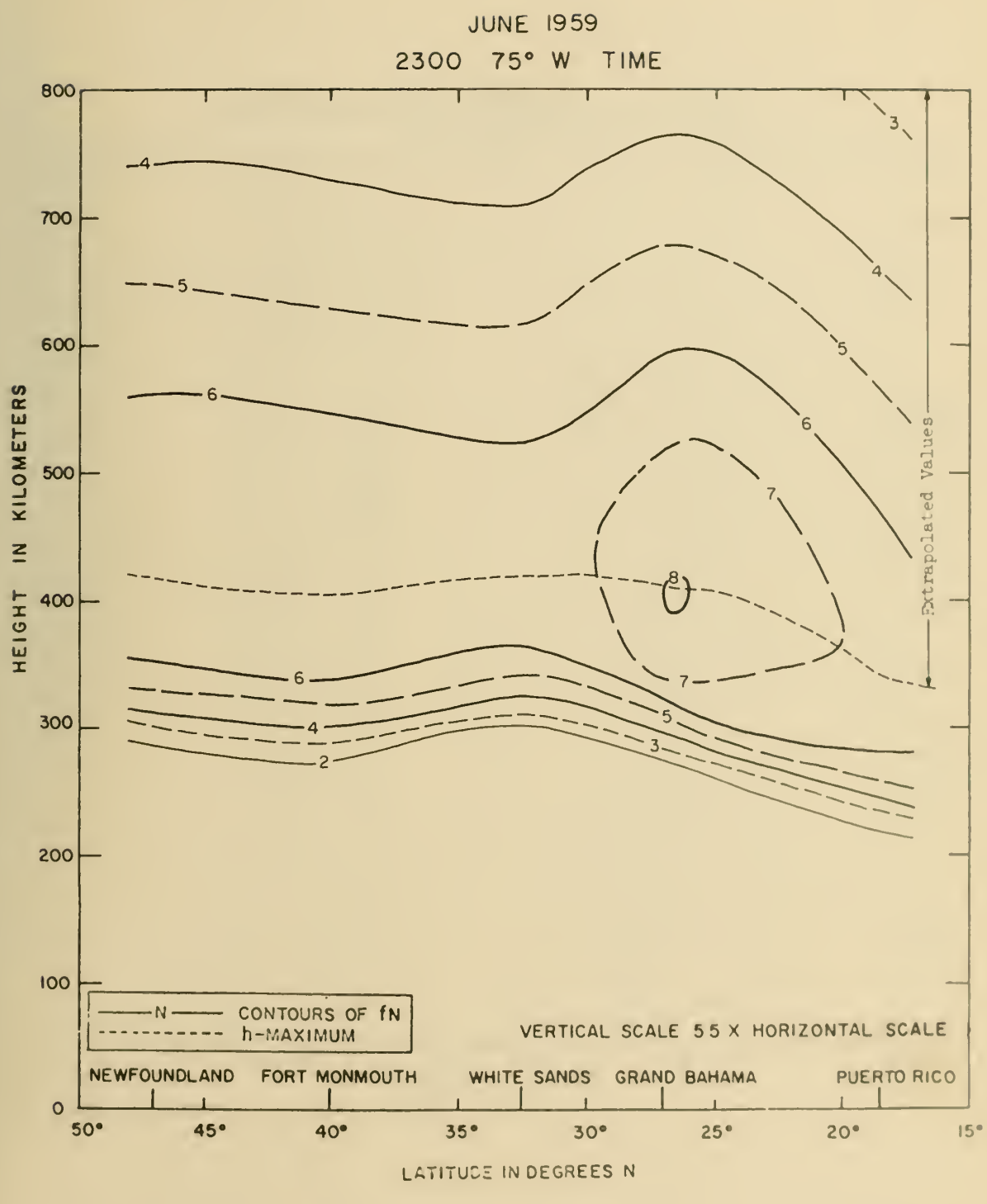

JUNE 1959
1800 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
-4
5
6
7
8
9
10
11
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

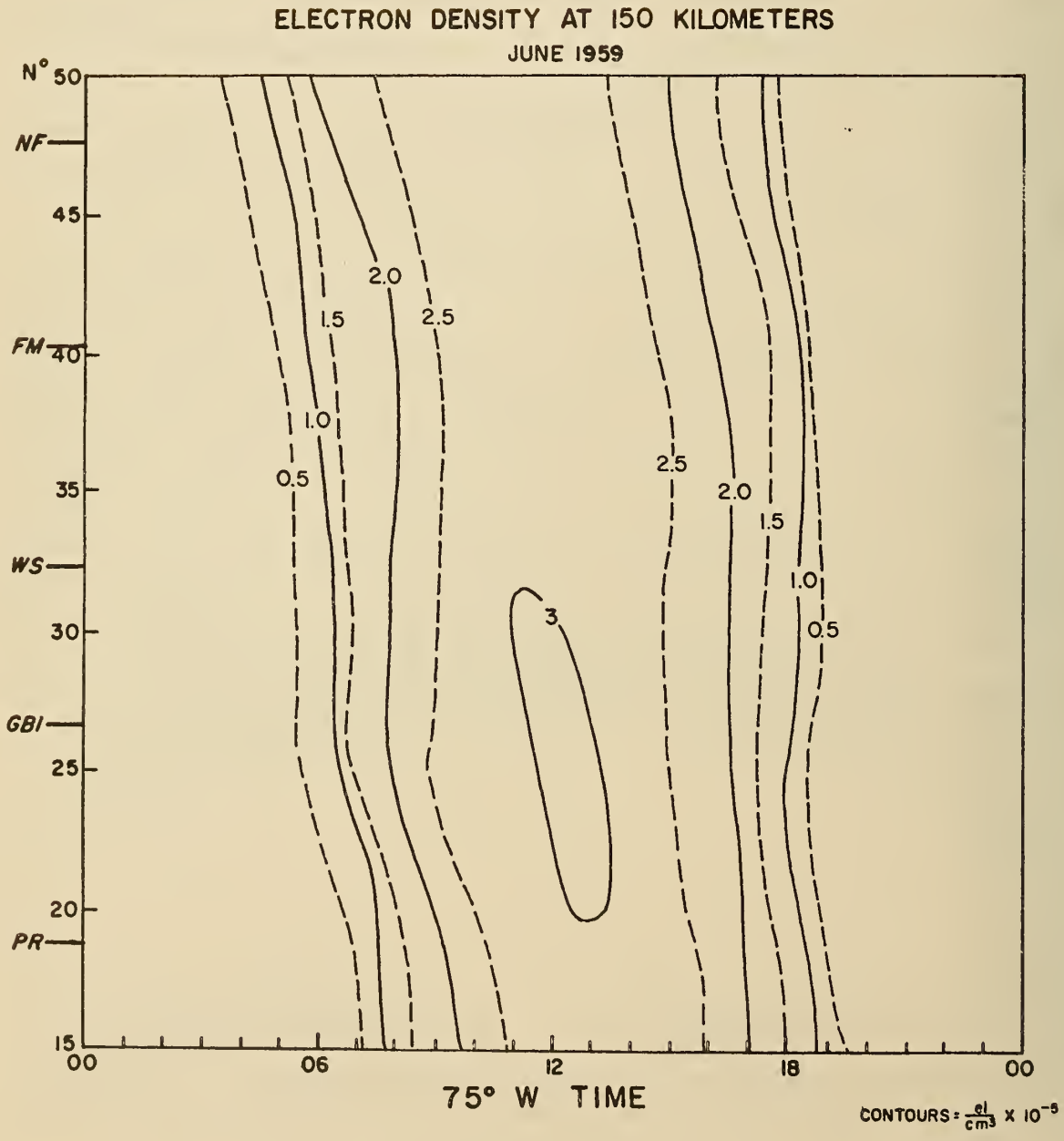

JUNE 1959
1900 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

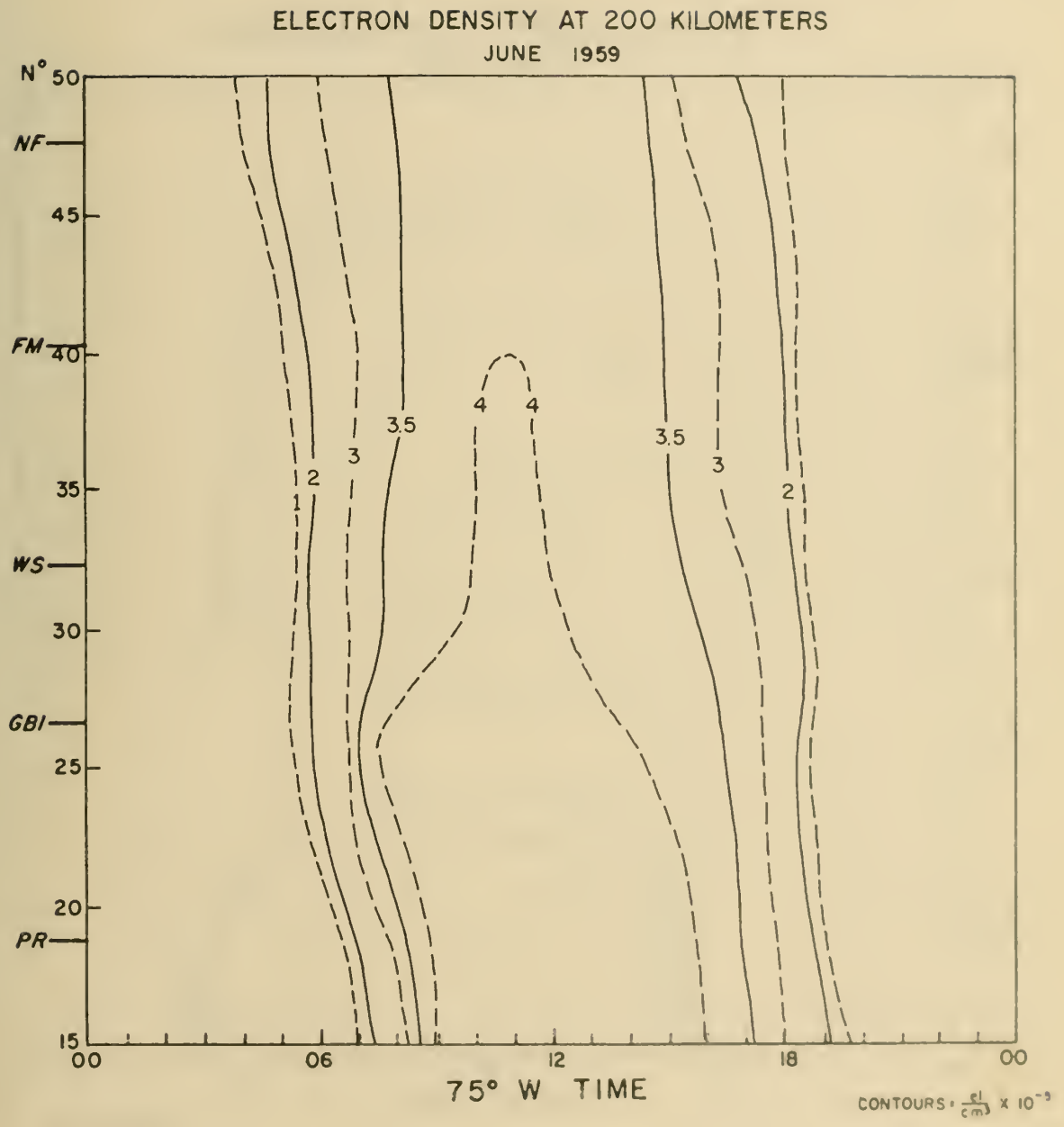

JUNE 1959
2000 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
4
5
6
7
8
3
2
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

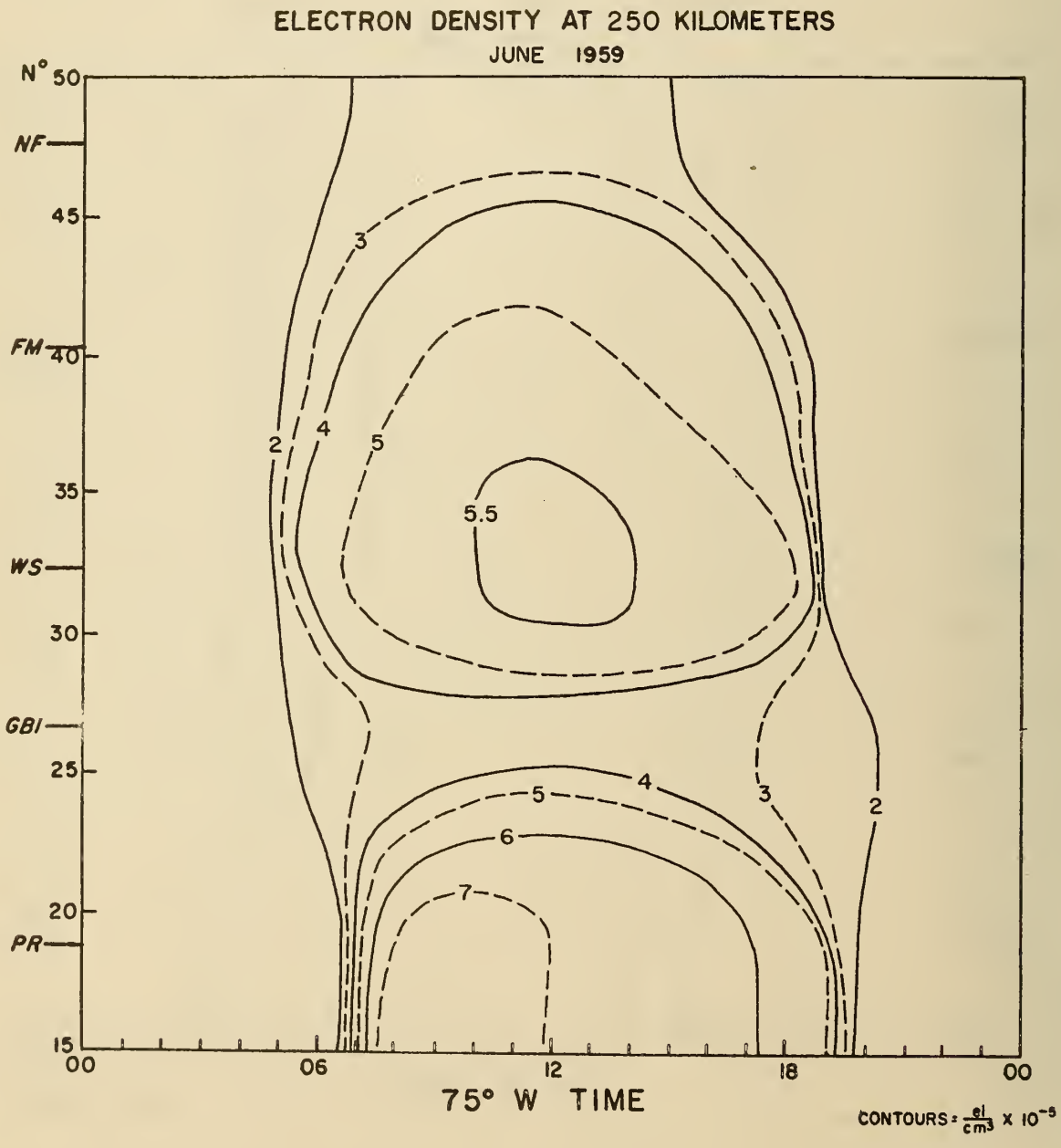

JUNE 1959
2100 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

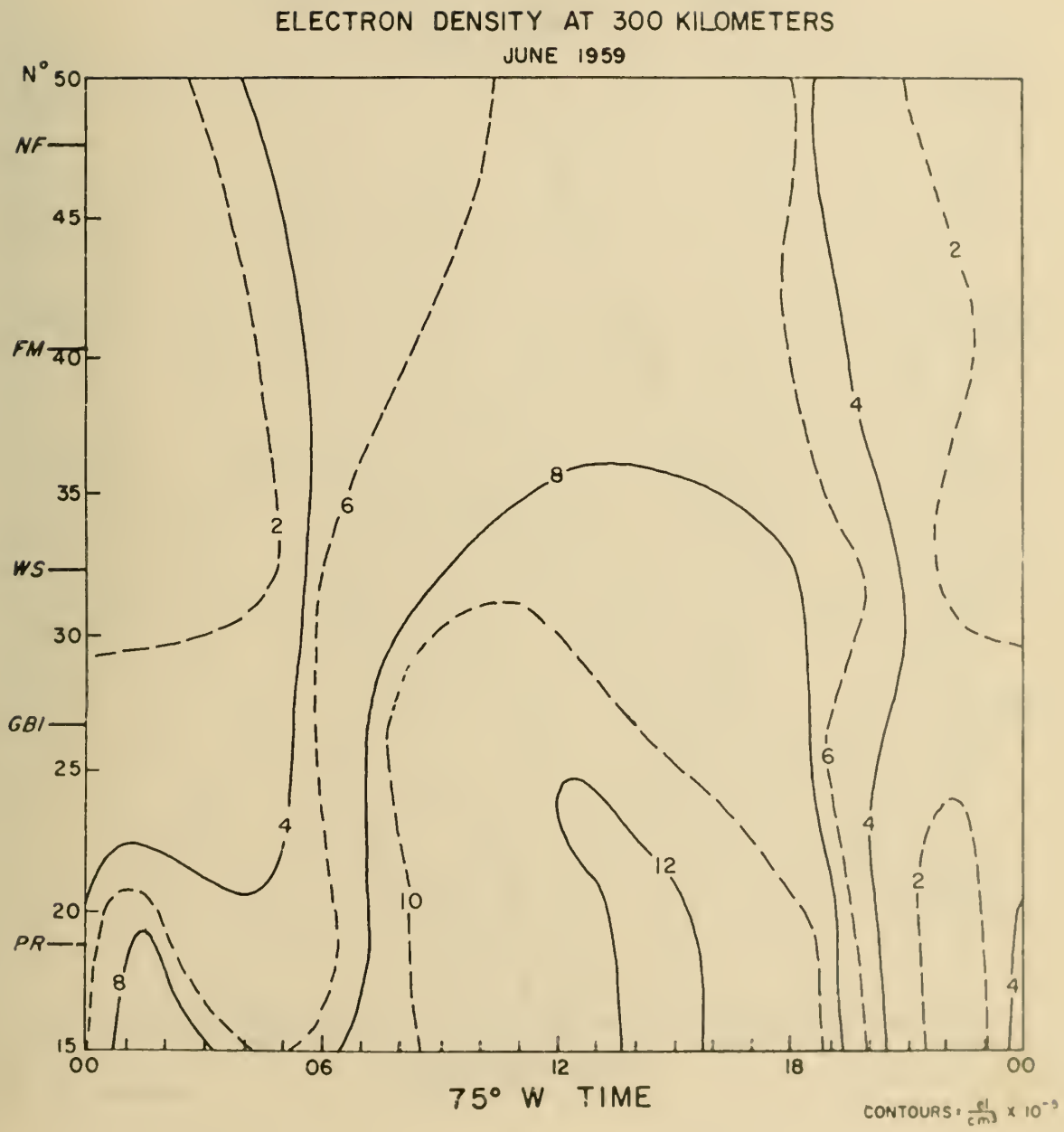

JUNE 1959
2200 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 5.5 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

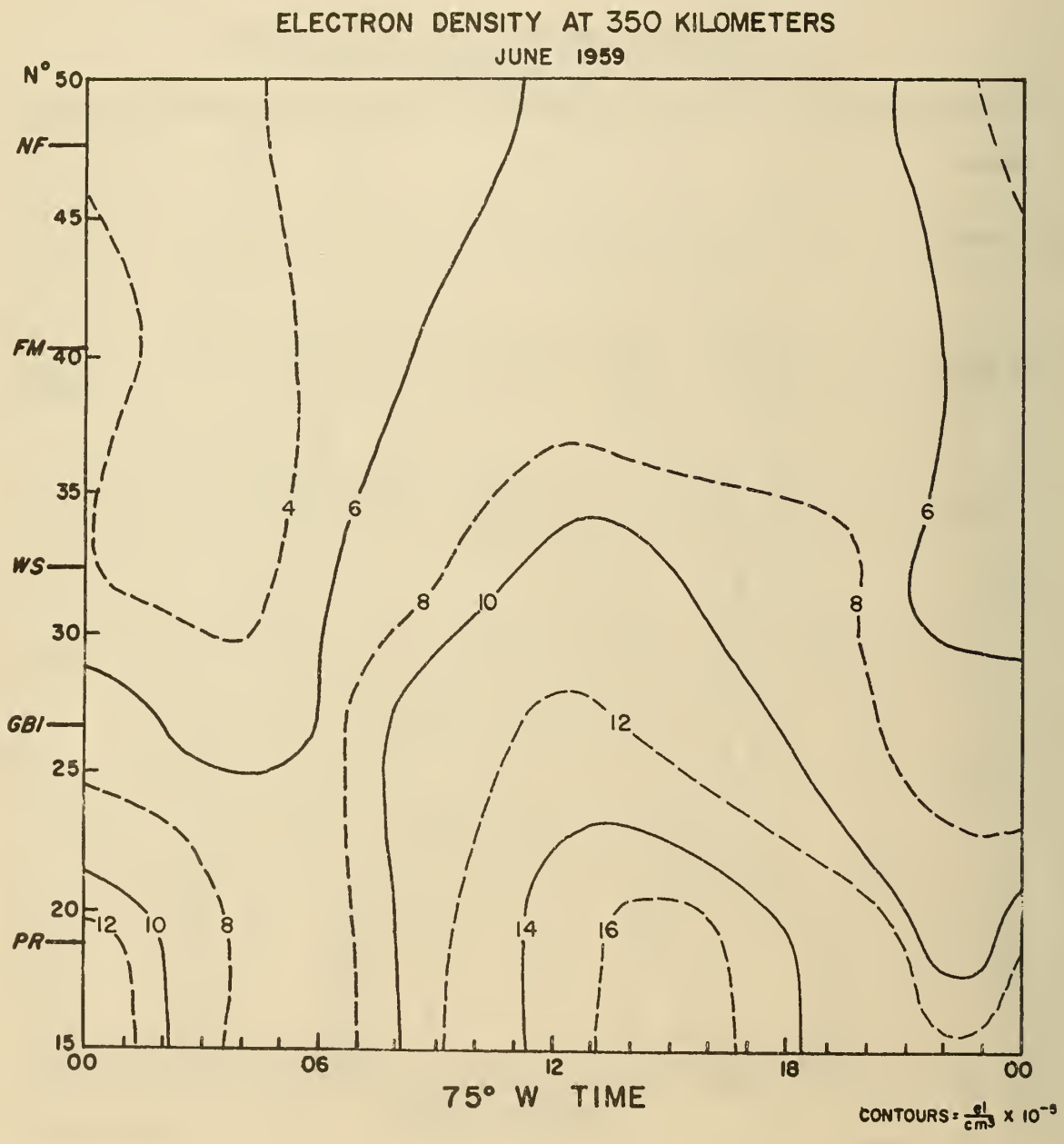

JUNE 1959
2300 75° W TIME
HEIGHT IN KILOMETERS
800
700
600
500
400
300
200
100
0
Extrapolated Values
N CONTOURS OF fN
h-MAXIMUM
VERTICAL SCALE 55 X HORIZONTAL SCALE
NEWFOUNDLAND
FORT MONMOUTH
WHITE SANDS
GRAND BAHAMA
PUERTO RICO
50°
45°
40°
35°
30°
25°
20°
15°
LATITUDE IN DEGREES N

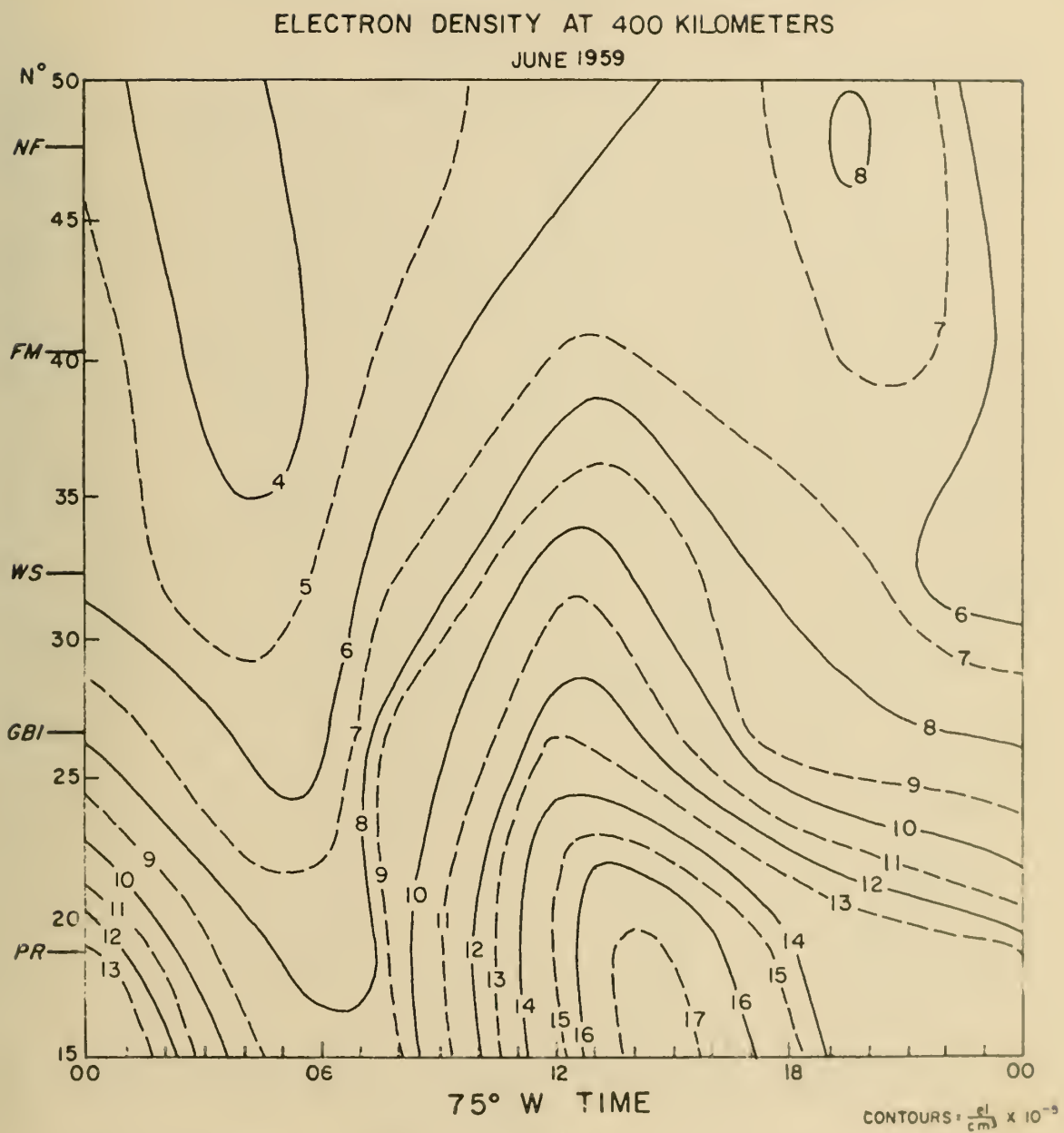

ELECTRON DENSITY AT 150 KILOMETERS
JUNE 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
0.5
1.0
1.5
2.0
2.5
3
2.5
2.0
1.5
1.0
0.5
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ X 10⁻⁵


ELECTRON DENSITY AT 200 KILOMETERS
JUNE 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS: el/cm³ x 10⁻⁹
1
2
3
3.5
4
4
3.5
3
2


ELECTRON DENSITY AT 250 KILOMETERS
JUNE 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm3 X 10⁻⁵
2
3
4
5
5.5
6
7

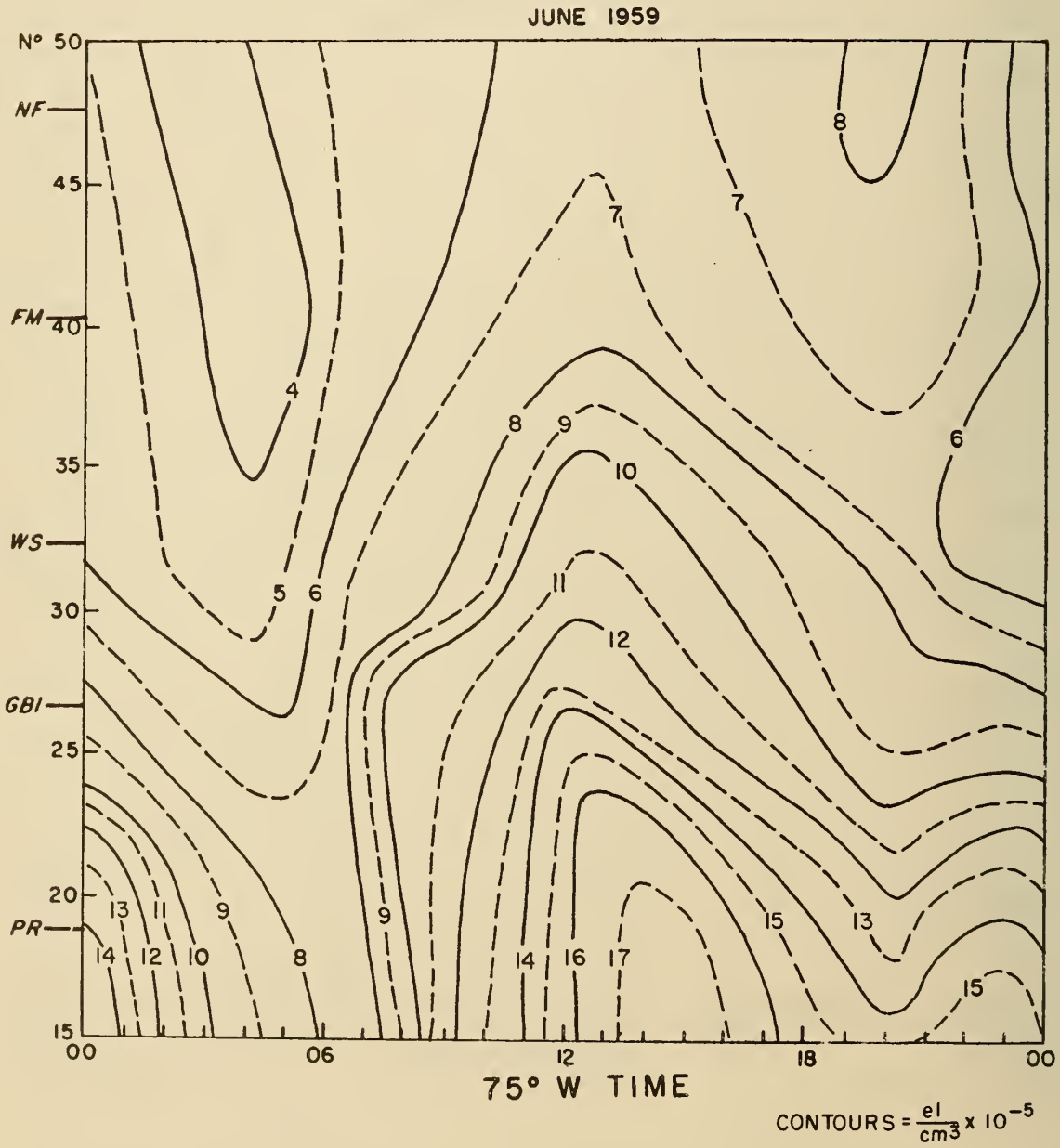

ELECTRON DENSITY AT 300 KILOMETERS
JUNE 1959
N° 50
NF
45
FM 40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ x 10⁻⁵
2
4
6
8
10
12


ELECTRON DENSITY AT 350 KILOMETERS
JUNE 1959
N° 50
NF
45
FM
40
35
WS
30
GBI
25
20
PR
15
4
6
8
10
12
14
16
00
06
12
18
00
75° W TIME
CONTOURS = el/cm3 x 10⁻⁵

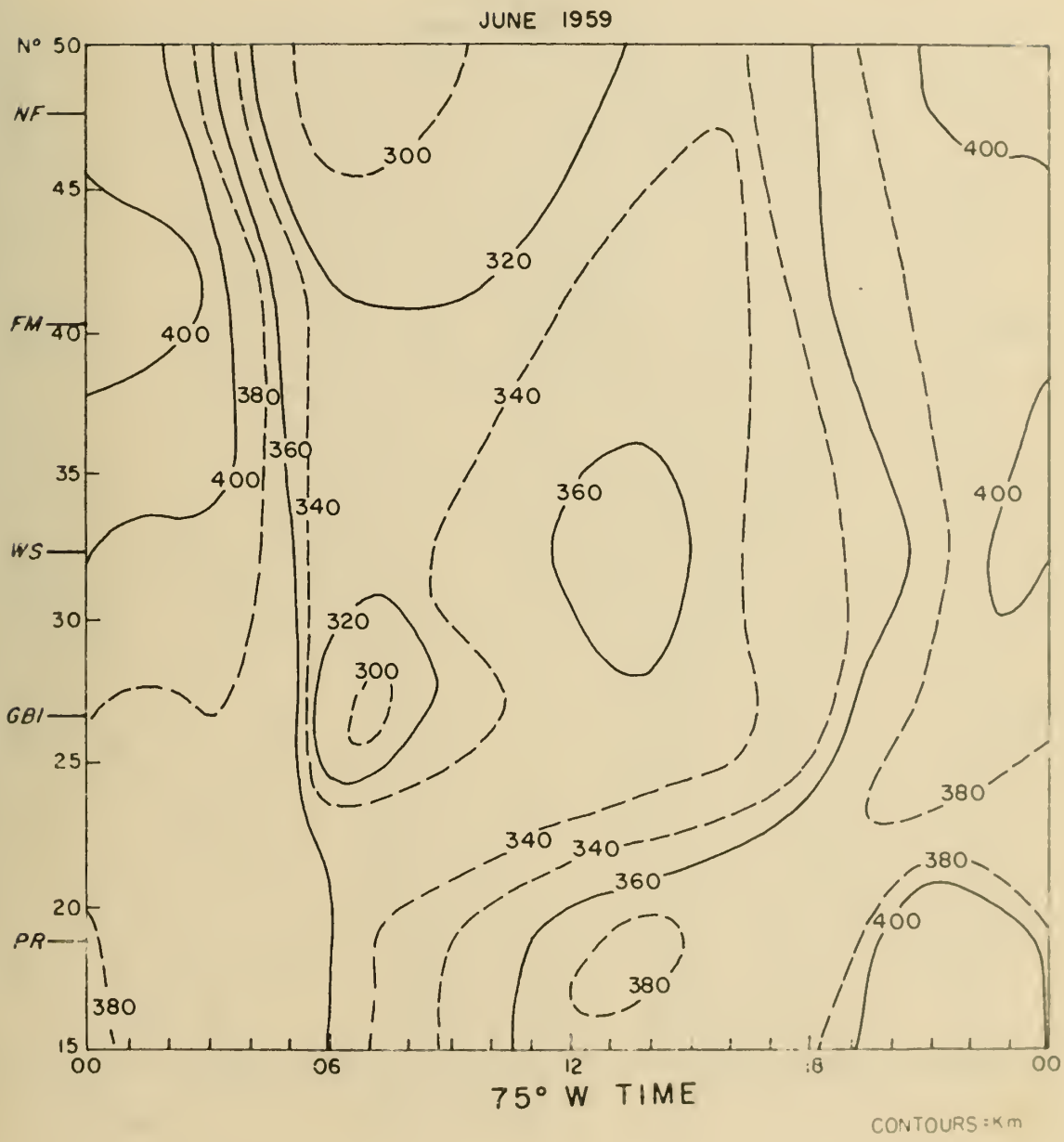

ELECTRON DENSITY AT 400 KILOMETERS
JUNE 1959
N° 50
NF
45
FM 40
35
WS
30
GBI
25
20
PR
15
00
06
12
18
00
75° W TIME
CONTOURS = el/cm³ x 10⁻⁵

MAXIMUM ELECTRON DENSITY

NMAX



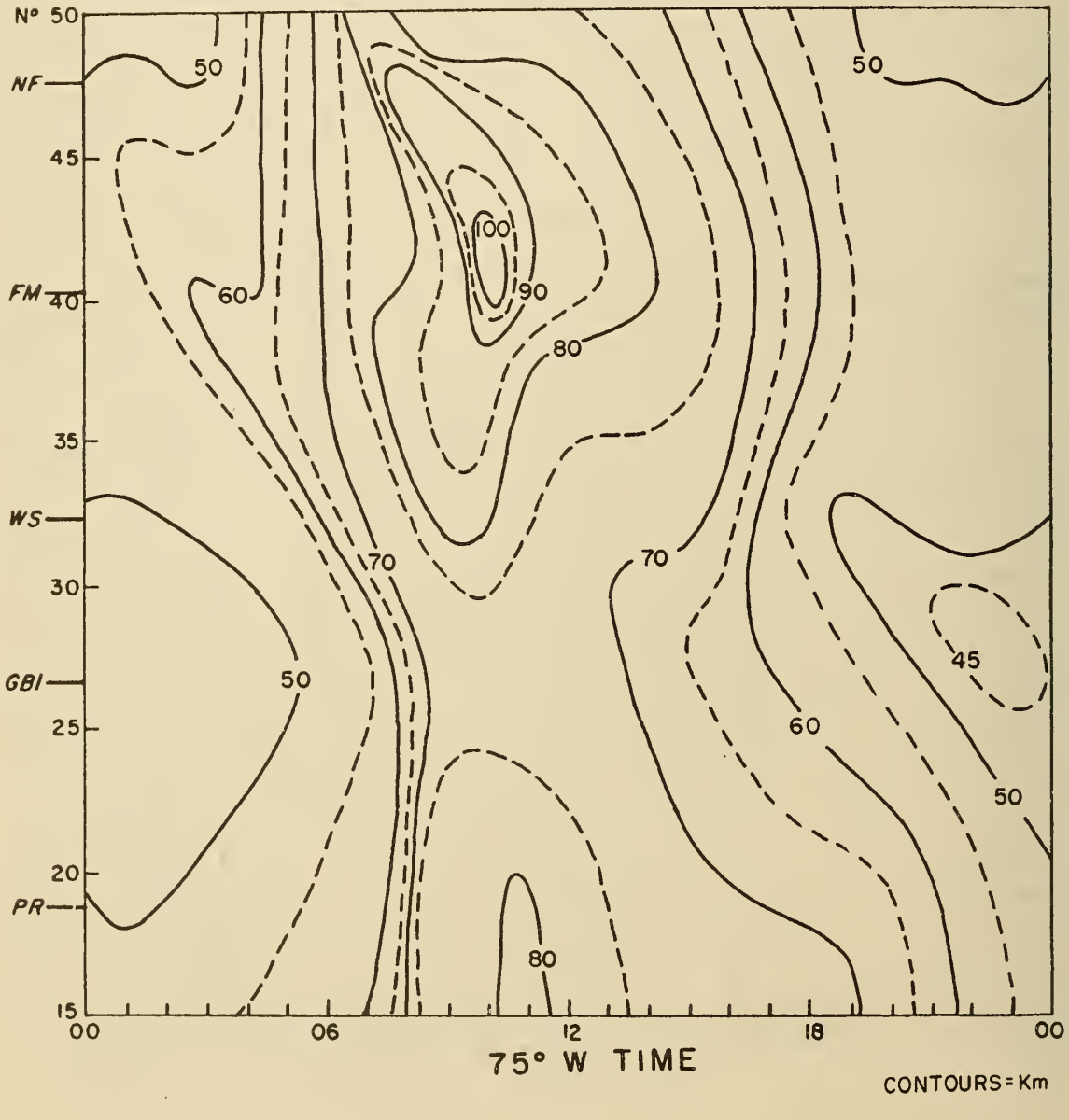
HEIGHT OF MAXIMUM ELECTRON DENSITY
HMAX



QUARTER THICKNESS OF F-REGION PEAK

SCAT

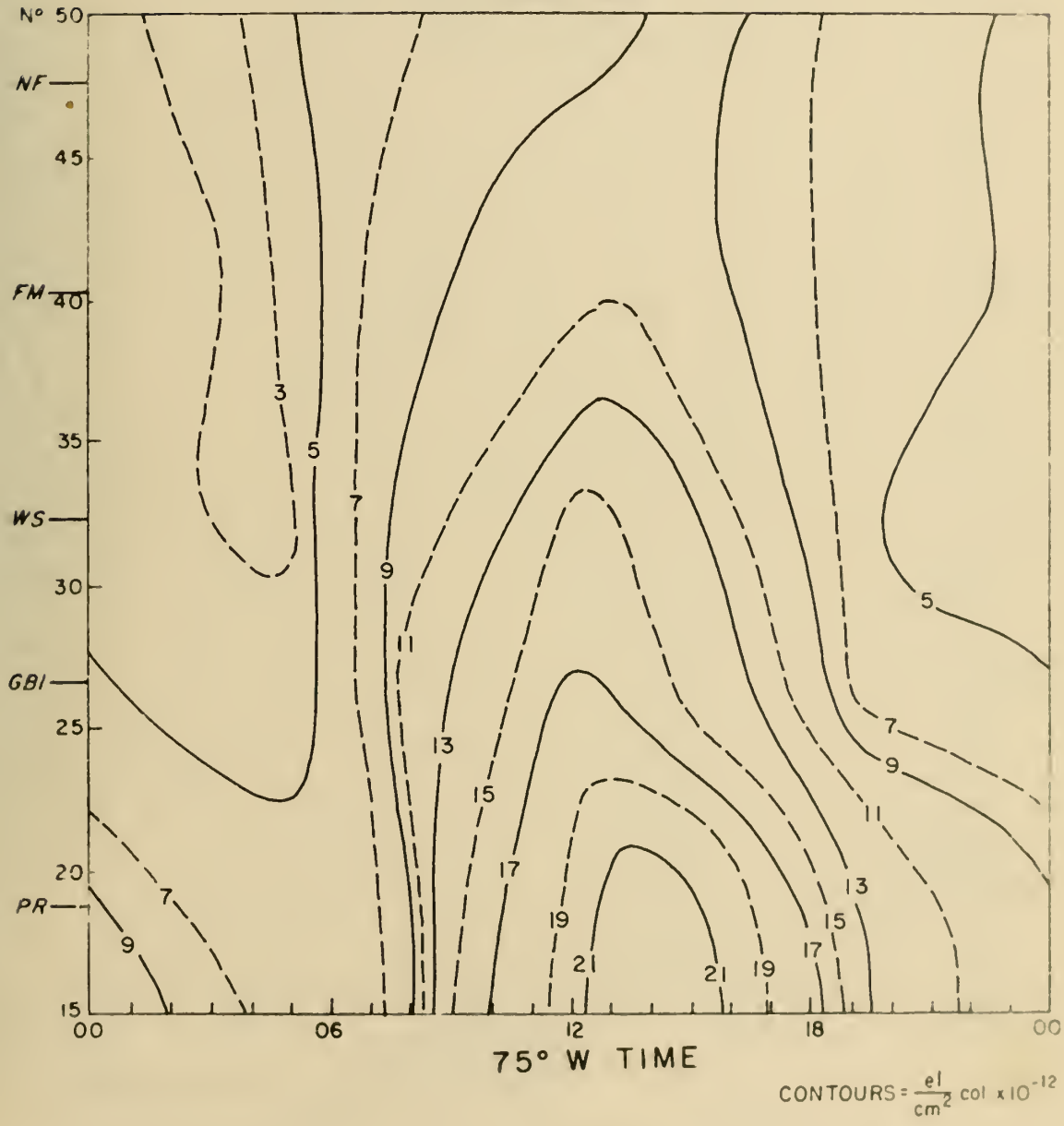
JUNE 1959



ELECTRON DENSITY INTEGRATED TO HEIGHT OF MAXIMUM ELECTRON DENSITY

SHMAX

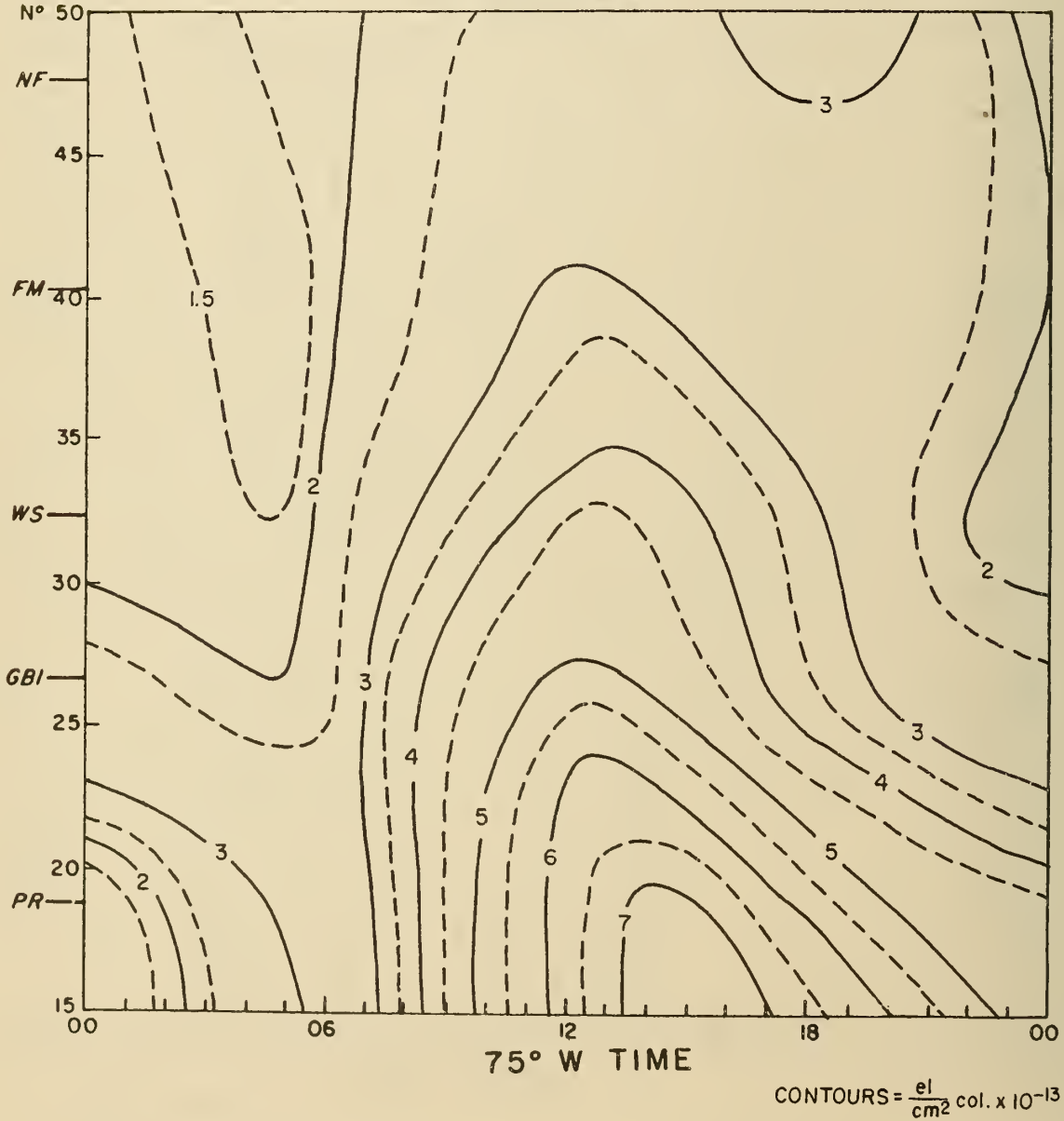
JUNE 1959



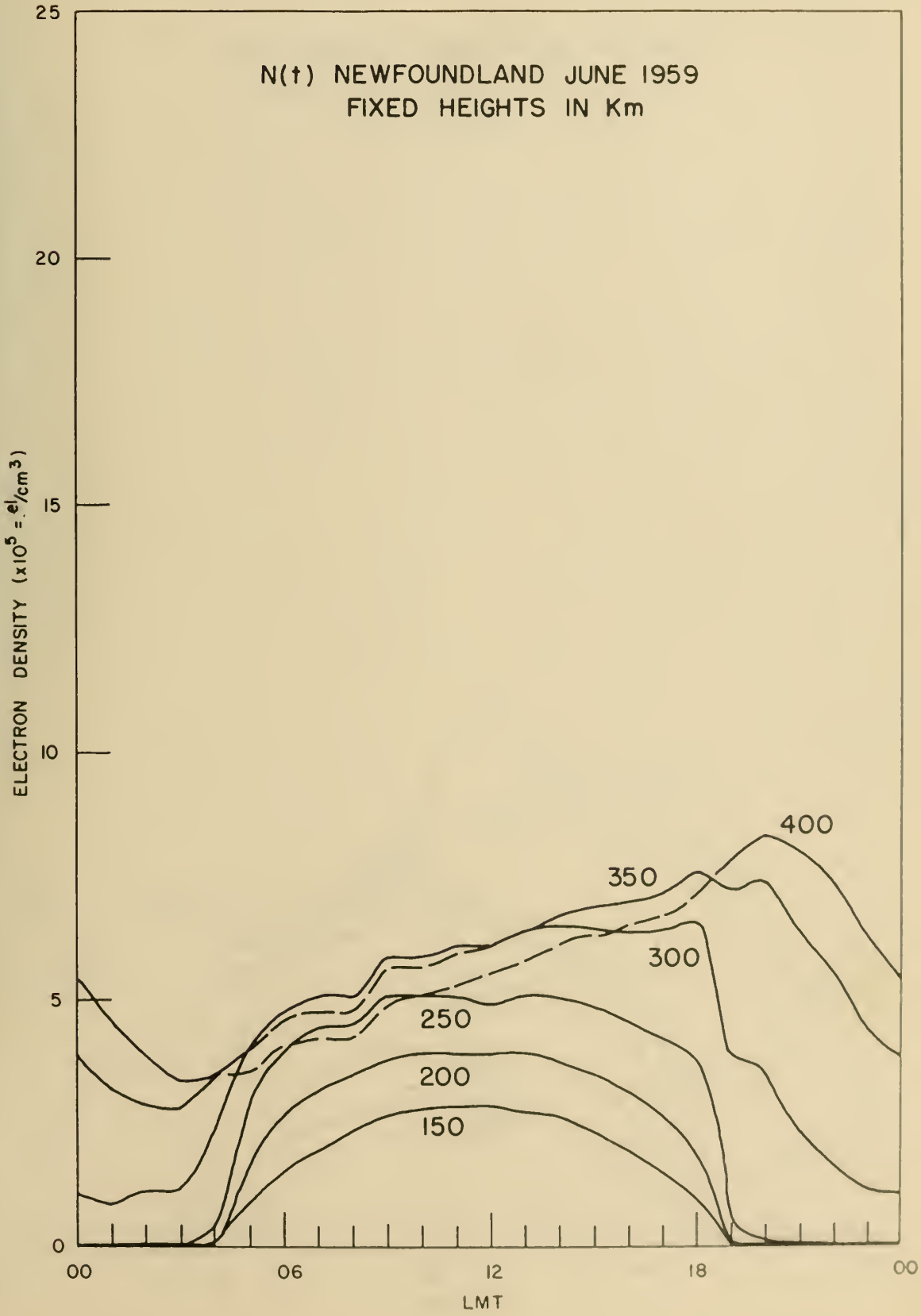
ELECTRON DENSITY INTEGRATED TO INFINITY

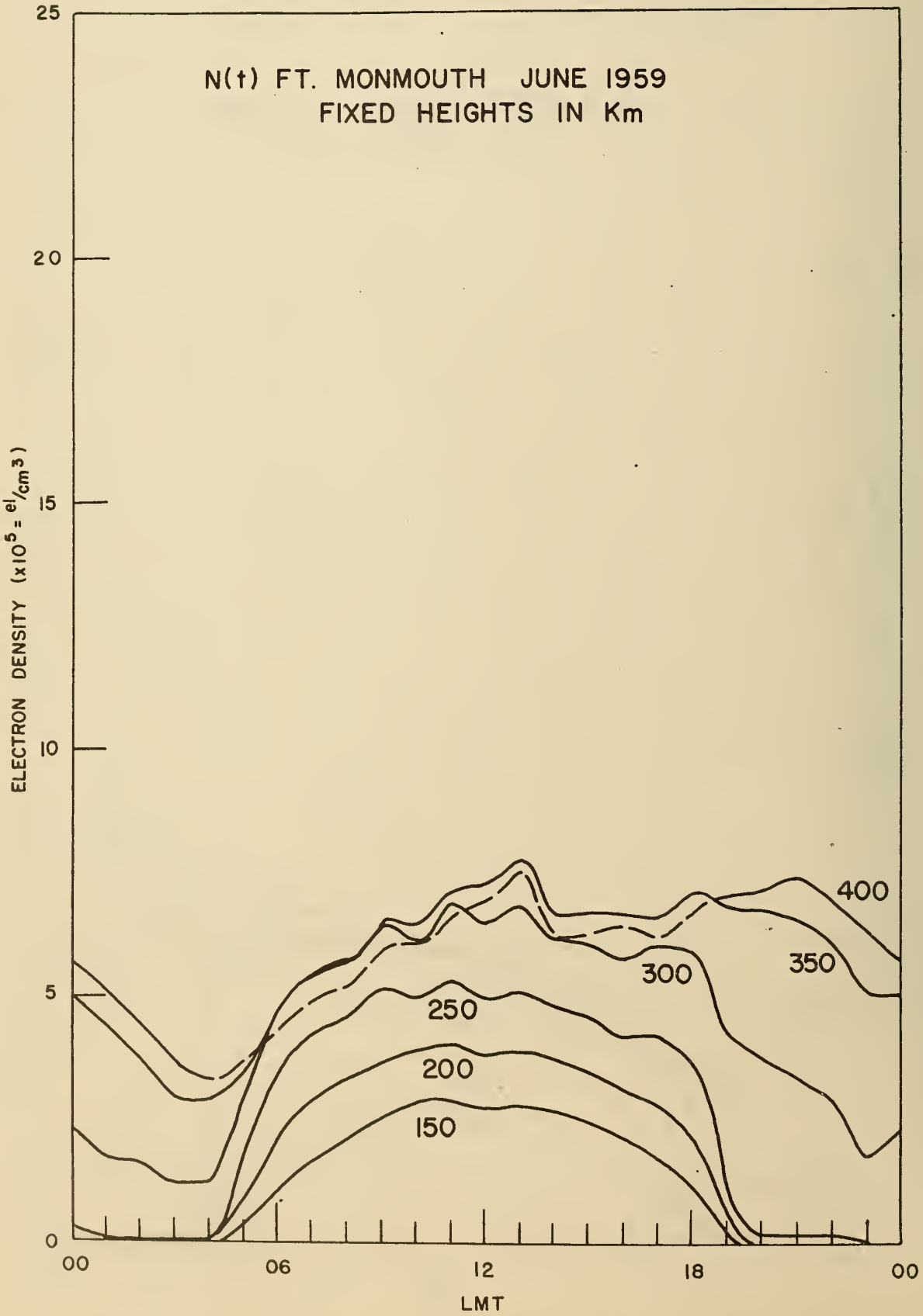
SHINF

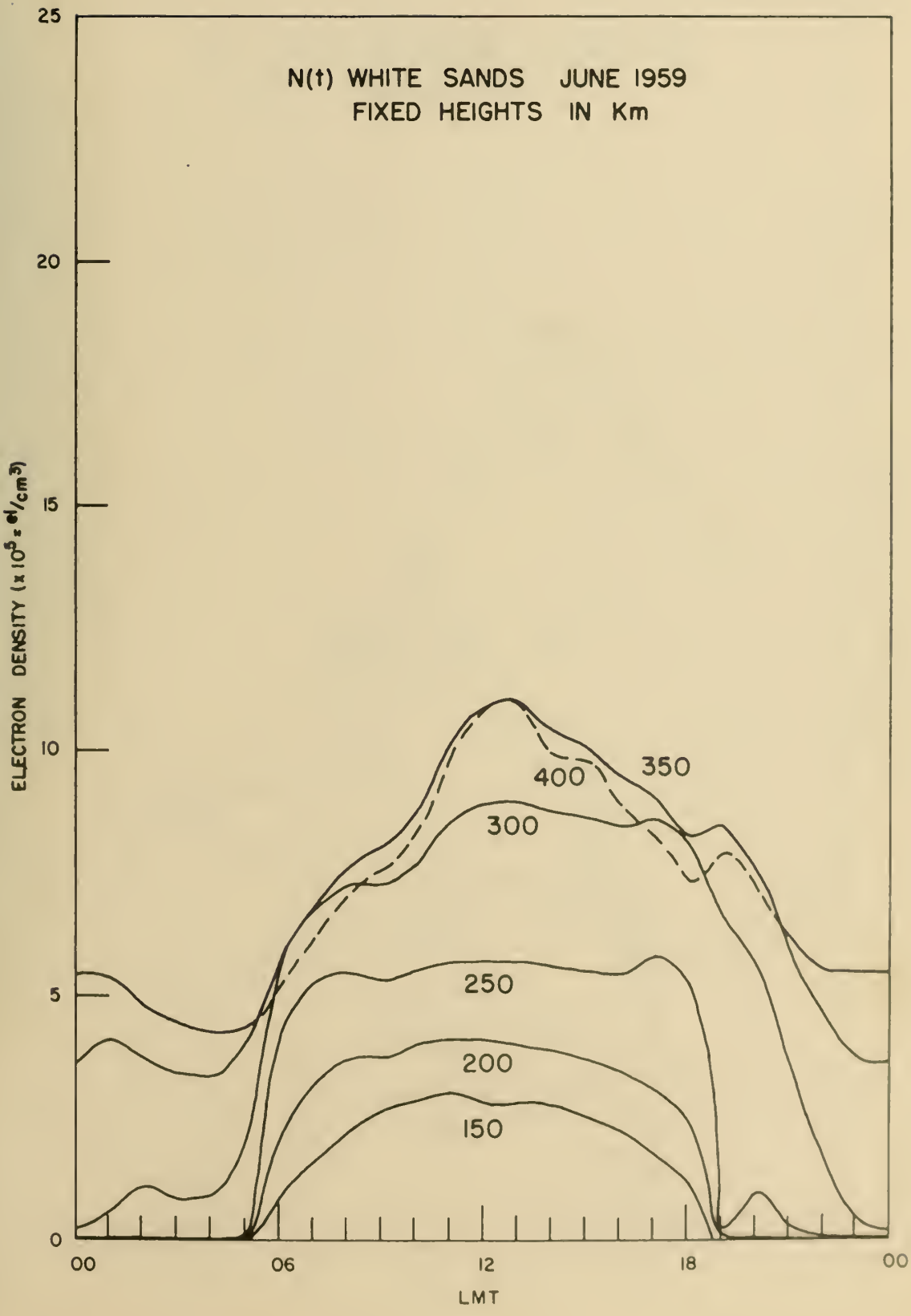
JUNE 1959

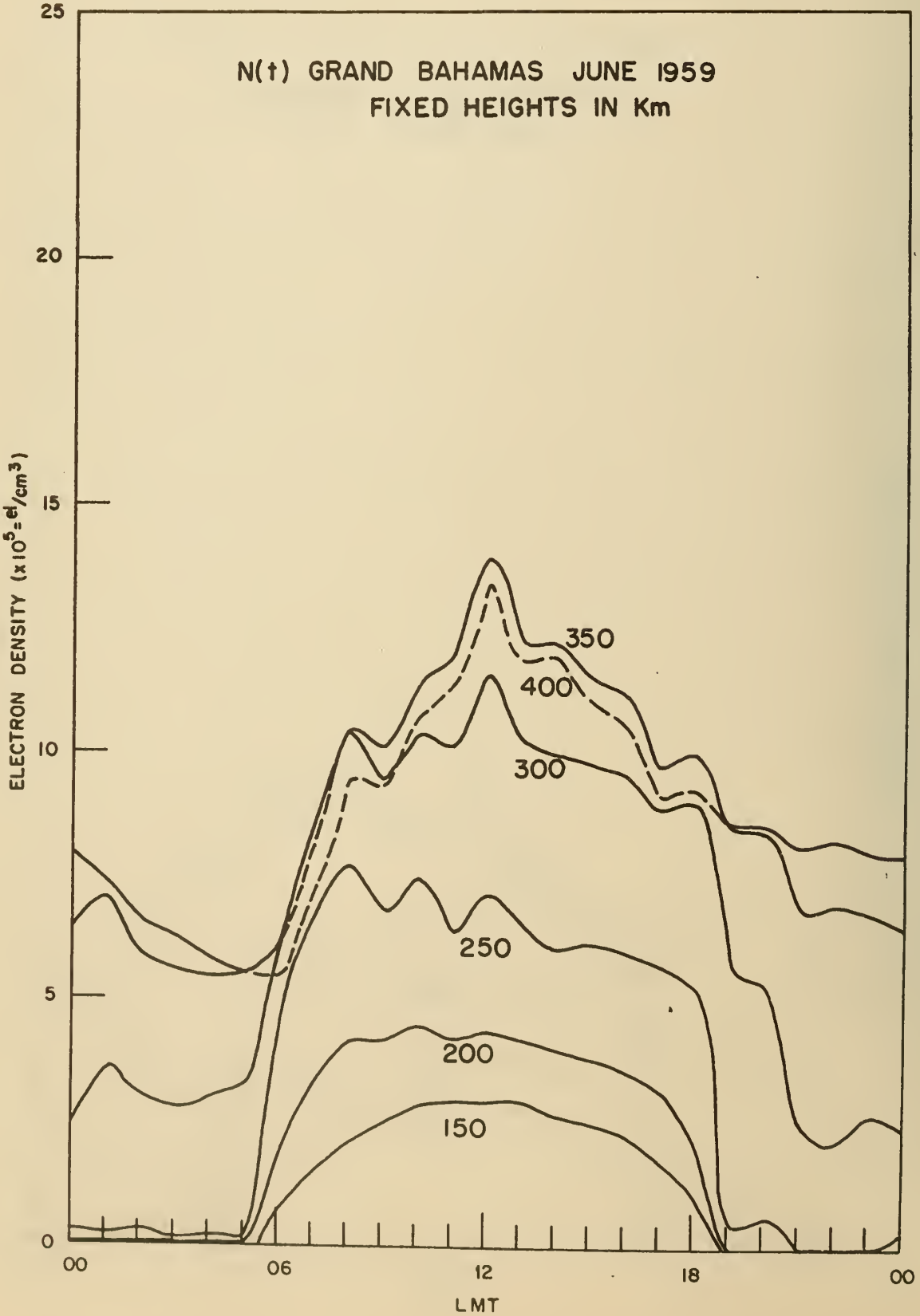


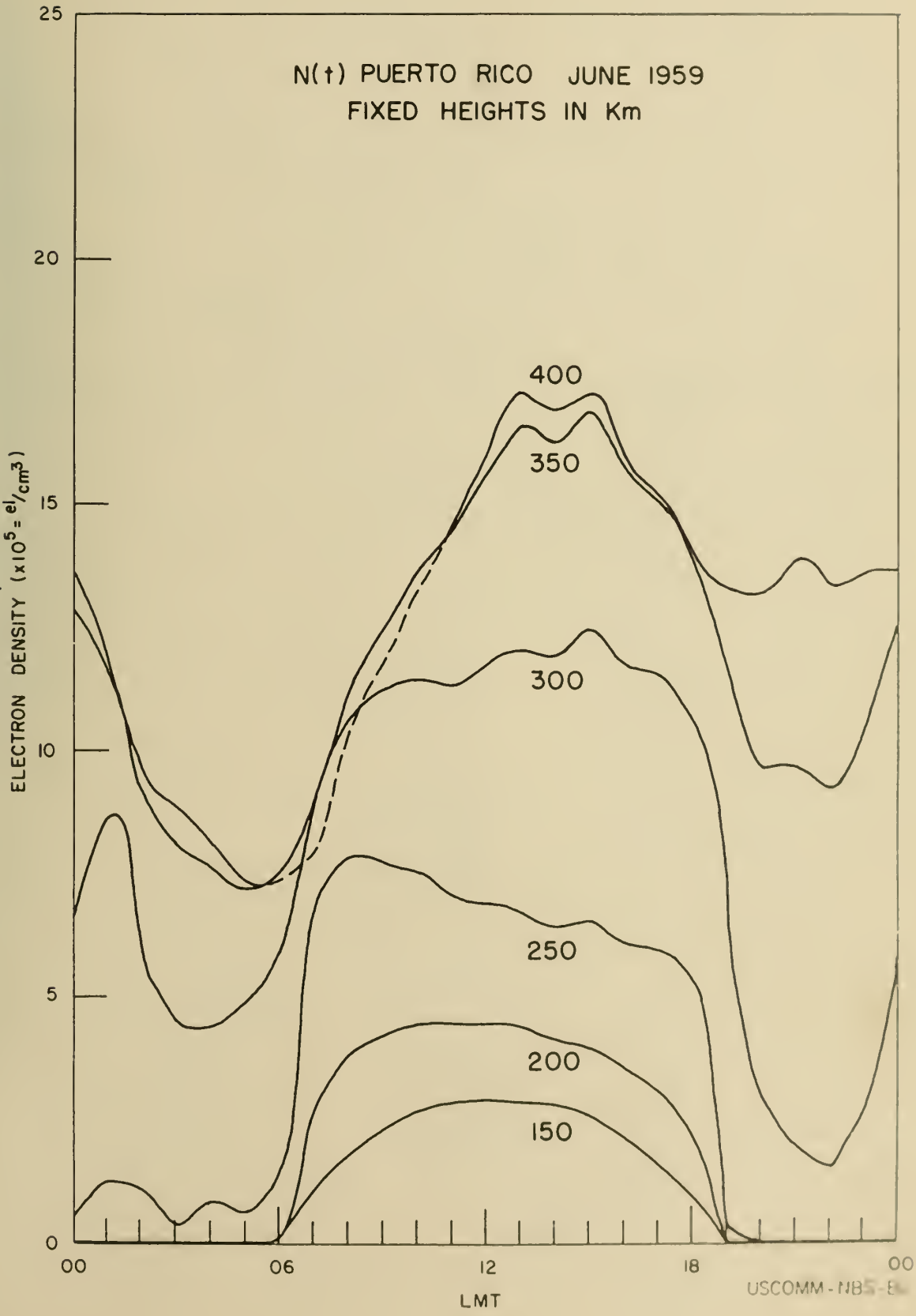
CONTOURS = $\frac{el}{cm^2}$ col. x 10^{-13}


N(t) NEWFOUNDLAND JUNE 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10^5 = el/cm^3)
25
20
15
10
5
0
400
350
300
250
200
150
00
06
12
18
00
LMT


N(t) FT. MONMOUTH JUNE 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10^5 = el/cm^3)
25
20
15
10
5
0
00
06
12
18
00
LMT
400
350
300
250
200
150


N(t) WHITE SANDS JUNE 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x 10⁵ = e⁻/cm³)
25
20
15
10
5
0
00
06
12
18
00
LMT
350
400
300
250
200
150


N(t) GRAND BAHAMAS JUNE 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10^5=el/cm^3)
25
20
15
10
5
0
350
400
300
250
200
150
00
06
12
18
00
LMT


N(t) PUERTO RICO JUNE 1959
FIXED HEIGHTS IN Km
ELECTRON DENSITY (x10⁵ = el/cm³)
25
20
15
10
5
0
400
350
300
250
200
150
00
06
12
18
00
LMT
USCOMM-NBS-B

U.S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Analytical Chemistry. Inorganic Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Radiometry. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry. Molecular Structure and Radiation Chemistry.

• Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionospheric and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS